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CONTENTS

PAGE

FRONTISPIECE : ONE OF THE 60 MW HYDROGEN-COOLED SETS IN USKMOUTH POWER STATION - - - - - - - - - - - - - 2

PROGRESS AND DEVELOPMENT, 1953 :

POWER EQUIPMENT - - - - - - - - - - - - - 3
MINING GEAR - - - - - - - - - - - - - 20
MATERIALS HANDLING - - - - - - - - - - - - 26
ROLLING MILLS - - - - - - - - - - - - - 28
INDUSTRIAL AND GENERAL ELECTRIFICATION - - - - - - - - - 29
TRANSPORT : LAND, SEA AND AIR - - - - - - - - - 33
ELECTRONIC MACHINE CONTROL - - - - - - - - - - 40
PLASTICS - - - - - - - - - - - - - - 41
INDUSTRIAL AND DOMESTIC HEATING EQUIPMENT - - - - - - 42
INSTRUMENTS - - - - - - - - - - - - - 47
TELECOMMUNICATIONS - - - - - - - - - - - 49
LAMPS AND LIGHTING - - - - - - - - - - - 55

THE EFFECT OF HEAT TREATMENT ON THE ELECTRICAL PROPERTIES OF GERMANIUM 63
By R. J. Hodgkinson

DEVELOPMENT OF ELECTRIC WHALING FORERUNNERS - - - - - - - 71
By Reginald Bean

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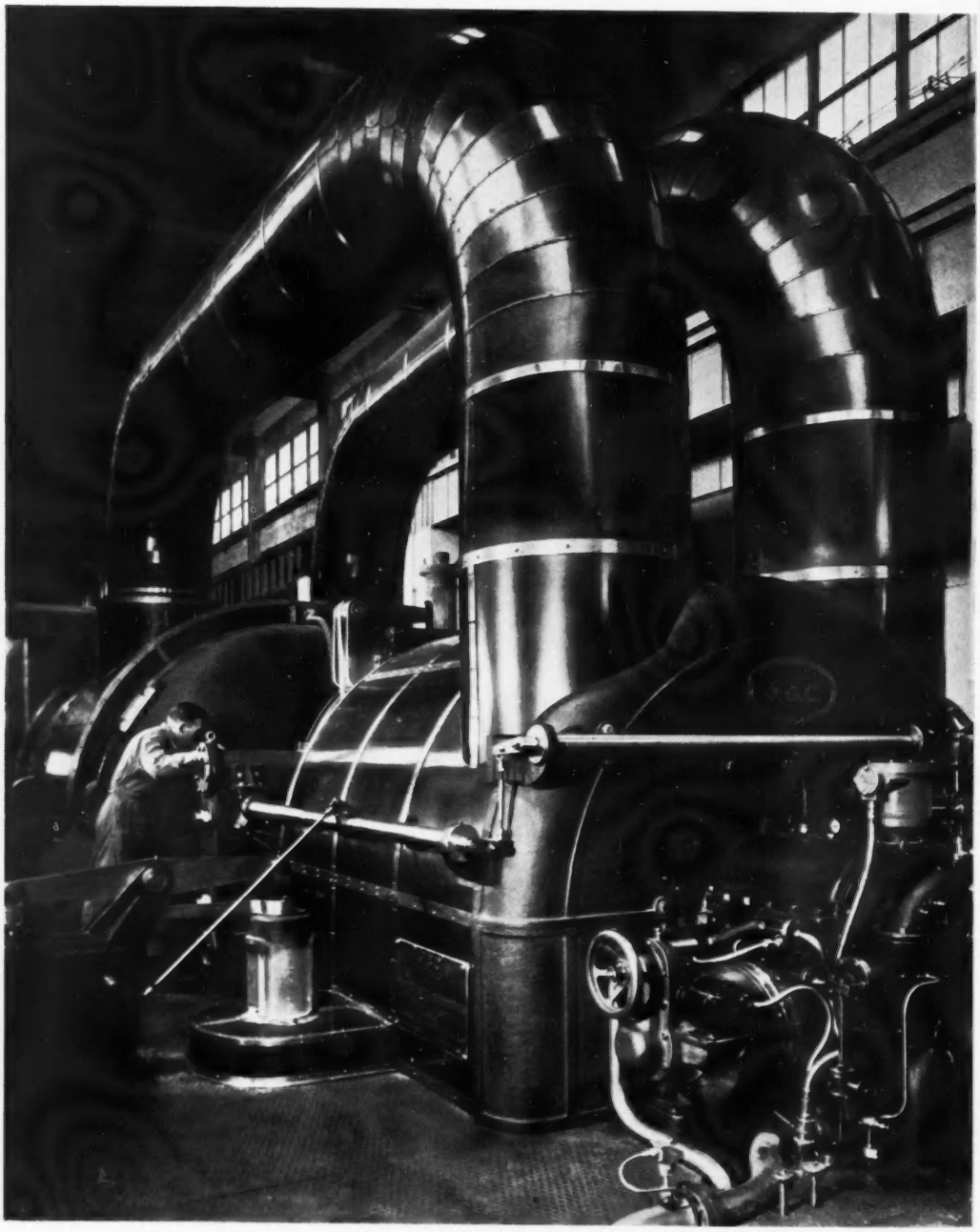

One of the record-breaking 60 MW hydrogen-cooled sets in Uskmouth Power Station.

Progress and Development, 1953

Power Equipment

GENERATORS AND COMPRESSORS.

During the past year the demand for power plant, both from the British Electricity Authority and from industry, has continued, and orders for over 160 MW of plant have been received.

Contracts for two further 60 MW hydrogen-cooled turbo-generator sets have been placed: one for the Bold "B" Station, St. Helen's, South Lancashire, in the Merseyside and North Wales Division of the B.E.A.; the other for Hams Hall "C" Power Station, Birmingham, bringing the total in course of construction for that station up to six. These sets are being built to the standard B.E.A. steam conditions of 900 lb. per sq. in. gauge and 900 deg. F. total temperature.

The decision to increase the ultimate capacity of the Huncoat Station, Accrington, to 150 MW has resulted in a further 30 MW set being ordered. Generation is at 11 kV, 0·74 power factor; steaming conditions are 600 lb. per sq. in. gauge and 850 deg. F. total temperature. The first two sets at this station have been in constant service for the past twelve months (fig. 1).

The 360 MW Uskmouth Power Station was officially opened in October last by the Mayor of Newport, Councillor William Pinnell, B.E.M., with the first two 60 MW hydrogen-cooled sets supplying 120 MW to the Grid. Recent tests have shown the first of these two sets to be working at the highest efficiency ever recorded for power generators of this size operating at a steam pressure of 900 lb. per sq. in., and a steam temperature of 900 deg. F. The British Electricity Authority has officially confirmed a heat consumption figure for these sets at full output of 9,027 B.Th.U. per kWh. One of these sets is illustrated in the frontispiece. When completed, this will be one of the largest power stations, not only in this country, but in Europe. A full description of the equipment supplied to this station formed the subject of an article in this Journal, October, 1953.

At the Woolwich Power Station, the fifth 30 MW, 22 kV turbo-alternator is in commission, as also are the two further 11 kV sets of this rating at Doncaster and Huddersfield.

Recent orders for industrial plant include three 10 MW, 11 kV sets for Colvilles, a 15 MW

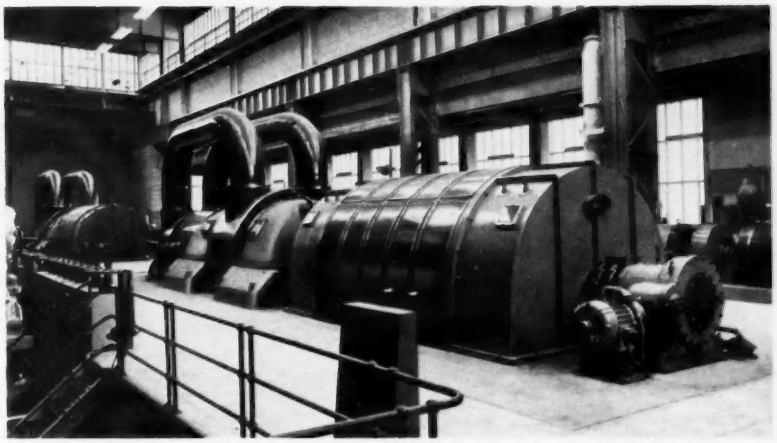

Fig. 1.—Two 30 MW turbo-alternators in the Huncoat Power Station, Accrington.

set for installation at the Cleveland Iron Works of Dorman Long & Co. Ltd., and a 5 MW set for Guest Keen & Baldwins Iron & Steel Co. The last named machine is required to supply process steam at a pass-out pressure of 155 lb. per sq. in. and is to be used in their East Moors Works, Cardiff.

Of the industrial plants put into service during the period under review, two are for paper mills in Scotland: one rated at 4 MW is installed at the Inveresk Paper Co., Ltd. and is capable of passing out 80,000 lb. of steam per hour at 30 lb. per sq. in. ; the other, a 5 MW, 3·3 kV set at Caldwells Paper Mill Co., Ltd., Inverkeithing, provides 100,000 lb. of process steam per hour at 20 lb. per sq. in. Other sets recently commissioned include a 6 MW, 11 kV unit for Sheepbridge Iron Co., Ltd., operating at a steam pressure of 600 lb. per sq. in., 800 deg. F., and passing out 56,000 lb. of steam per hour at 165 lb. per sq. in. ; and a 7·5 MW, 2·75 kV high-pressure turbo-alternator for the Skinningrove Iron Co., Ltd.

Overseas a considerable amount of plant has been commissioned during the past year. At the Orlando Power Station, Johannesburg, which will ultimately contain ten sets with a total output of 337·5 MW, the sixth generator is in course of erection. Two 7·5 MW sets for Bloemfontein Municipality are now in service and two further 10 MW sets are being built ; a 2 MW set for the Government of Orissa in connection with the Cuttack Thermal Scheme is now in commission, as is also the third 7·5 MW set for the Howard Generating Station, Wide Bay, Queensland, the three sets being seen in fig. 3. Two 2·5 MW turbo-alternators for the Mackay City Council, Queensland, are now being erected. Two 750 kW, 440 volt, back pressure, geared turbo-alternators have been put into service for Sena Sugar Estates, Ltd., at their Luabo Power Station, Portuguese East Africa. These sets are of interest in that the alternators are of the totally enclosed air-cooled type with the air coolers situated on top of the alternators.

An important event in the field of design during the past year has been the development of a new centrifugal compressor. Fig. 4 shows a general view of a model of this compressor which can either be directly coupled to a turbine or driven by an electric motor through gearing. The air enters the compressor at the coupling end and is discharged through a volute at the outer end. The impellers are of orthodox design and construction, consisting of disc, cover plate and backward-inclined blades which are riveted between disc and cover plate. The impellers discharge into a diffuser passage fitted with vanes designed to give the maximum conversion

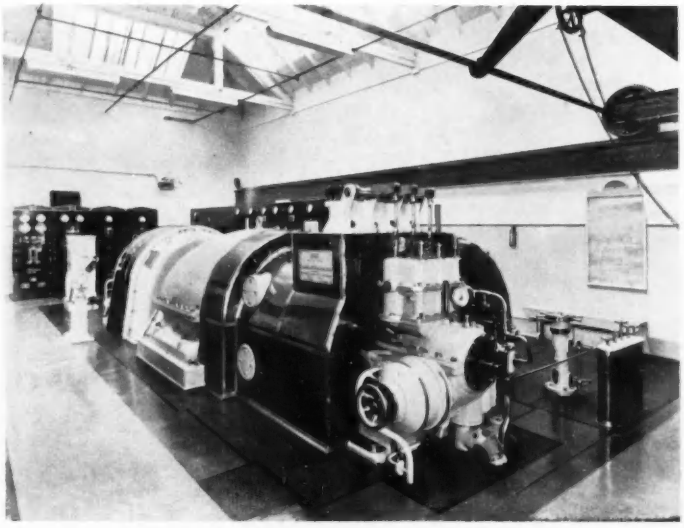

Fig. 2.—3,000 kW direct coupled pass-out turbo-alternator at Henry Bruce and Son Paper Mill, Midlothian. The turbine passes out 55,000 lb./hr. of process steam at 25 lb. per sq. in. pressure.

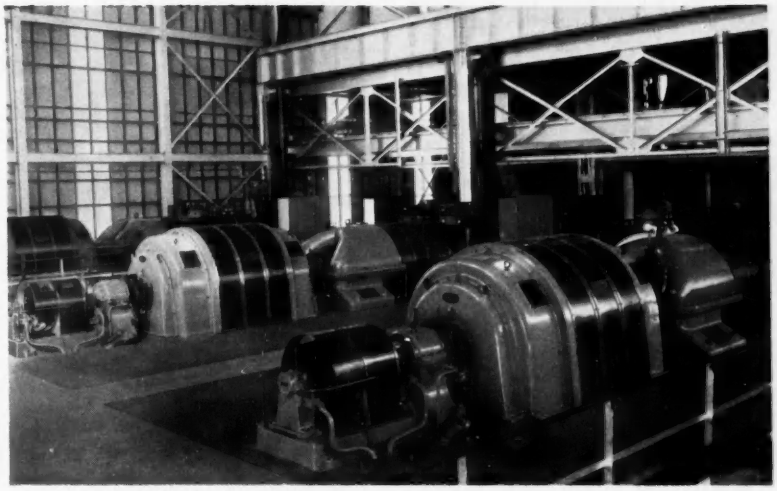

Fig. 3.—Three 7,500 kW turbo-alternators in the Howard Power Station, Maryborough, Queensland.

of kinetic into pressure energy. In all but the first and last stages, the air leaving the diffusers is suitably guided into four coolers arranged at 90° circumferentially around the stage. Such an arrangement ensures that the air enters the coolers with a minimum of disturbance and that maximum heat transmission is assured.

There are, in all, five cooled stages, having a total of twenty small, easily handled identical cooler nests. Five cooler nests are contained in each of four interchangeable mild steel fabricated cooler boxes bolted to the compressor casing. The cooling water is supplied to the tube nests by means of a common water header built into each cooler box. The coolers are so arranged that all tube nests can be removed from above the engine room floor and a spare tube nest inserted in a minimum of time. A complete cooler box containing five nests can also be easily removed and used as a bath for cleansing the air side of the tubes when necessary. The arrangement of cooler boxes also enables the width of the horizontal joint to be kept to a minimum, and the top half casing, together with its associated cooler boxes, can be removed by merely breaking the horizontal joint and four main cooling water-pipe joints at the ends of the compressor.

Interstage labyrinth packings are provided on the impeller cover plate hub and on mild steel

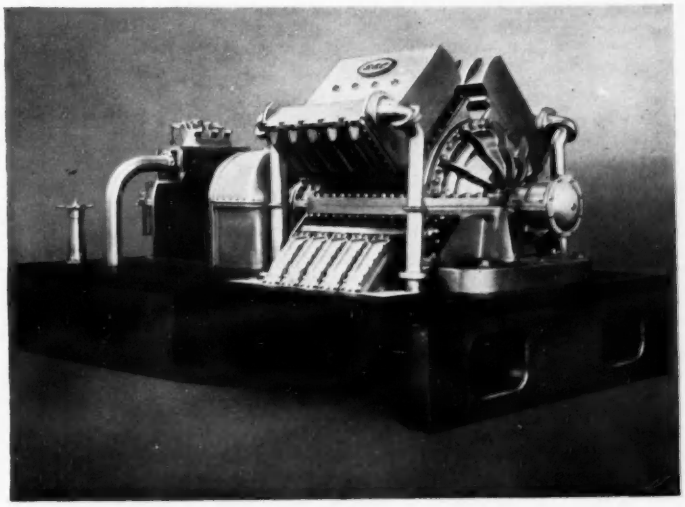

Fig. 4.—Model of the new design of turbo-compressor.

sleeves on the shaft; these run in a white metalled bush with small running clearances thus reducing leakage to a minimum. After the last impeller there is a balance piston to counteract thrust, the remainder of which is absorbed by a separate thrust bearing.

Two compressors of this type are on order for the National Coal Board for Moseley Common Colliery, each capable of delivering 10,000 cu. ft./min. of air against a pressure of 80 lb./sq. in. gauge. The compressor is driven through speed increasing gears by a 2,250 b.h.p. synchronous motor. It is to be noted that a compressor of this design to deliver 20,000/25,000 cu. ft./min. of air is now in course of development.

A number of 4,485 h.p. and 5,400 h.p. synchronous motor-driven turbo-compressors have been commissioned in South Africa; five are for the Anglo-American Corporation, three being for use in the gold mines of the Orange Free State to deliver 20,000 cu. ft./min. of air against a pressure of 100 lb./sq. in. gauge, and one for the Brakpan mine which will deliver against a pressure of 85 lb./sq. in. There are also three compressors for Johannesburg Consolidated Investments for Freddies North Lease Areas, Ltd., for whom an order is in hand for a further equipment to deliver 25,000 cu. ft./min. of air against a pressure of 100 lb./sq. in. For the Harmony Gold Mining Co., of South Africa, a similar compressor is nearing completion.

At the Cleveland Works of Dorman Long & Co., Ltd. a further turbine-driven blower has been installed to deliver 90,000 cu. ft./min. of air at a pressure of 30 lb./sq. in. gauge.

A 2,200 h.p. synchronous motor to drive a rotary compressor has recently been delivered for service in the nitric acid plant at the dynamite factory of African Explosives and Chemical Industries, Ltd., in the North Rand (fig. 5). An interesting feature of the drive is that the motor operates in tandem with a gas turbine designed to burn a fuel which is a by-product of the chemical plant. Normally the turbine will assist in driving the compressor and the load on the motor will be only 670 h.p. Alternatively the motor may have to run the plant for long periods, when its full output will be required. The equipment is designed to operate at unity power factor at an altitude of 5,400 ft., the maximum ambient temperature being 40 deg. C. (104 deg. F.).

Fig. 6.—Wound stator for one of three 25 MW vertical shaft alternators for the Errochty Power Station of the North of Scotland Hydro-electric Board.

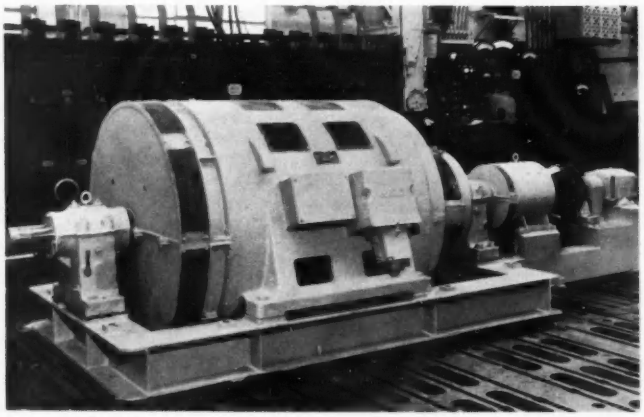

Fig. 5.—2,200 h.p., 6·6 kV, 1,500 r.p.m. synchronous motor to drive a rotary compressor for the African Explosives and Chemical Industries, Ltd.

LOW EXCITATION LIMITING EQUIPMENT FOR ALTERNATORS.

Where an alternator is provided with an automatic voltage regulator, sudden changes in output due to load variations or switching operations may result in the regulator reducing the excitation of the machine below the critical limit for stable operation. Such changes in output are always accompanied by a movement of the terminal voltage vector relative to the

vector representing the rotor pole axis, the angle between these two vectors being known as the internal machine angle. This angle increases with a drop in excitation or an increase in load and is the fundamental criterion of excitation stability.

An equipment has been developed whereby resistance is inserted automatically in series with the control coil of the voltage regulator immediately this angle exceeds a predetermined value. Thus the setting of the regulator is adjusted until the machine excitation is restored to the desired value. On the resumption of normal operation, the resistance is cut out and the automatic voltage regulator again operates at its normal setting.

The internal machine angle is supervised by a phase-sensitive relay which actuates the motor-driven resistor in the control coil circuit of the automatic voltage regulator. One coil of the relay is energised from the terminals of the machine, and the other from a permanent magnet alternator which is directly coupled to the turbo-alternator shaft and produces a voltage in phase with the rotor pole axis.

By means of a phase-shifting device, zero torque of the relay can be made to occur at any desired angle between the two voltage vectors. This is known as the setting angle and corresponds to the required low limit of excitation.

An indicator in the control room provides continuous visual indication of the internal machine angle, while visual and audible warnings are given whenever corrective action is being taken or when the automatic voltage regulator is operating with a modified setting.

If the voltage regulator is out of service, the equipment gives warning of approaching instability and thus facilitates efficient hand control of the excitation. In these circumstances the warning signals are given earlier in order to provide a larger margin of safety for hand control, the relay being provided with two seettings which are selected by an auto/hand control switch.

HYDRO-ELECTRIC PLANT.

Two of the five 25 MW, 600 r.p.m. vertical shaft alternators for the Tungatinah power station of the Tasmania Hydro-electric Commission are now in service and erection of the third machine is nearing completion. For the Errochty Power Station of the North of Scotland Hydro-electric Board, the first of three machines has been delivered. These generators are also rated at 25 MW but run at a speed of 428 r.p.m. A completed stator is seen in fig. 6.

At the Pangani Falls Power Station in Tanganyika a further 5 MW horizontal shaft alternator, running at 750 r.p.m., has been commissioned, bringing the number of sets now in operation at this station up to five with a total output of 17·5 MW.

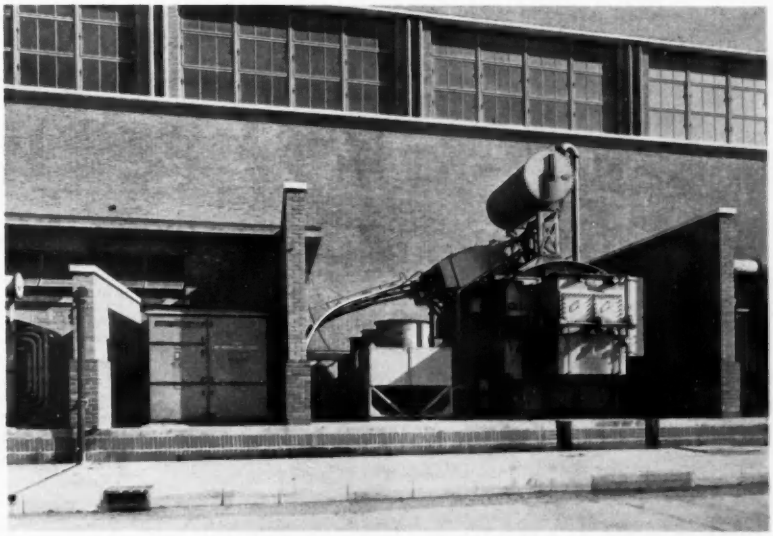

Fig. 7.—One of six 70 MVA generator-transformers, 11·8/140·7 kV at the Uskmouth Power Station.

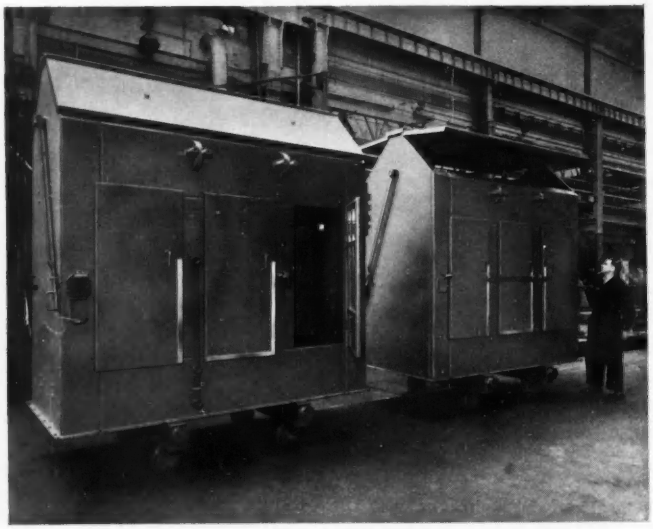

Fig. 8.—Two of the 1,500 kVA, 11,000/415 volt air-cooled transformers on test for the Ministry of Supply.

TRANSFORMERS AND REACTORS.

Recent contracts placed by the B.E.A. include a 72 MVA generator-transformer for Uskmouth "B" Power Station and two 20 MVA and two 10 MVA power transformers with on-load tapping switches. Of the six 70 MVA generator-transformers for Uskmouth "A" Power Station, the first two are in service, one being seen in fig. 7, while other transformers for the B.E.A. commissioned during the year include six 45 MVA units for outdoor sub-stations at Oldbury, Dorchester and Chichester.

Two 20 MVA, 33/6 kV transformers, which form part of an important extension to the electrical plant at the Whitehead Iron & Steel Co., Ltd., and six of the twelve 4,140 kVA furnace transformers for Albright & Wilson, Ltd., are now installed. The latter are arranged to operate in pairs, each pair supplying a 6-electrode type phosphorus furnace.

The first consignment of the Ministry of Supply contract for thirty 1,500 kVA air-cooled transformers has been delivered, two of these units being seen on test at the Works in fig. 8. The transformers are enclosed in vermin-proof housings, equipped with hand-operated ventilating flaps. These are interlocked with the associated circuit breakers so that the transformers cannot be put on load unless the flaps are open. When a transformer is out of service and the flaps are closed, heaters within the enclosure are automatically switched on to prevent condensation. Doors, fitted in the sides of

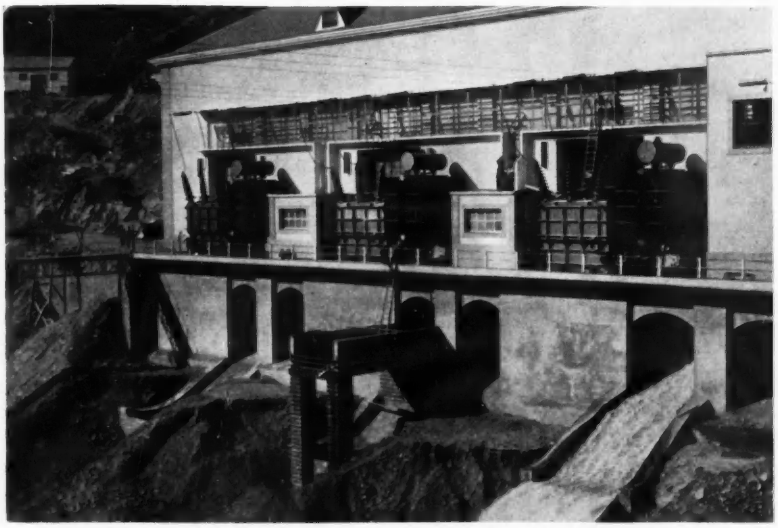

Fig. 9.—Three 16,000 kVA transformers at the Saltos del Sil Power Authority.

the housing, give access to the tap-changing links and are also of use for inspection purposes; protection of the transformers is afforded by thermostats which operate alarm and trip devices.

Of the overseas orders received, particular interest attaches to the one from Canada for fifteen transformers for the Toronto Hydro-electric System. Each is rated at 6,667 kVA with fan cooling and 5,000 kVA with natural cooling, and is designed for a voltage ratio of 13,200/4,160 volts. Certain novel features are embodied in the construction of these transformers. The cooling fans are mounted directly under the radiators and are automatically started by switches incorporated in the temperature indicating apparatus, while the on-load tapping switches are automatically operated to control the output voltage.

In Spain, the three 16,000 kVA, 6·6/138 kV transformers for the Saltos del Sil Power Authority are in service. They were specially built to meet the restricted space available on site and are shown in fig. 9. Another overseas order of interest which is nearing completion comprises a 1,500 kW rectifier transformer for the Victorian Railways, Melbourne. So far as is possible it is designed to form a self-contained unit. Fan speed-control chokes, and static exciters for the interphase transformers are mounted in a compartment on the side of the main transformer tank. The use of static exciters renders the interphase transformers independent of the D.C. load and thus eliminates the large rise in D.C. voltage normally experienced at very low loads.

Reference has already been made to the extensions to the electrical plant at the Whitehead Iron & Steel Co., Ltd., and the seven outdoor reactors involved in this scheme are in service. Six have a 3 per cent reactance on a throughput of 4,600 kVA, and the seventh has a reactance of 1·5 per cent on a throughput of 4,000 kVA.

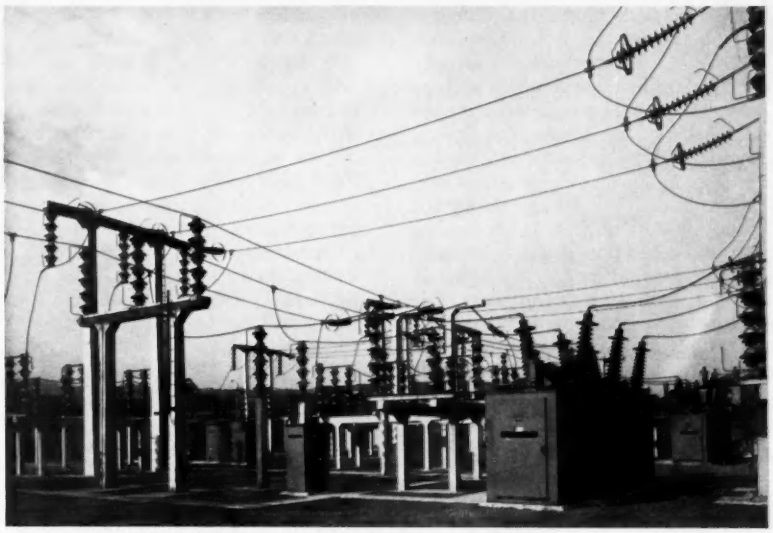

Fig. 10.—132 kV B.E.A. Substation at Oldbury showing the 2,500 MVA circuit breakers.

Two large saturable reactors form an important addition to the test plant at the Witton Engineering Works. These are now in commission and enable the largest rating of turbo-alternators for the British Electricity Authority to be tested at full voltage and current. Their maximum rating of 100 MVA is obtainable over a range of voltages covering normal supply systems. To meet tests at higher voltages, the reactors are insulated for 22 kV, but under these special conditions the loading is slightly restricted. These reactors are the largest of their type in the country, and have been specially designed to provide a smoothly variable load and to ensure that a sinusoidal current is drawn from the alternator.

OUTDOOR SWITCHGEAR.

Of the many contracts for outdoor switchgear for the B.E.A., the equipment for the new 132 kV switching stations at Smethwick and Oldbury is

now in service. The former is at present a three-switch station and an order has since been received for a fourth switching bay. For the Oldbury substation (fig. 10) the equipment includes two 45 MVA transformers, three 2,500 MVA oil circuit breakers, with associated isolators, control boards and protective equipment. This station is among the first to be arranged for supervisory control and is designed to permit future extensions to form a double busbar station.

A contract has also been placed for the complete electrical equipment for a further seven bays at the 132 kV B.E.A. substation at Smethwick, bringing the number of bays at this switching station up to fifteen. The new order covers seven 2,500 MVA oil circuit breakers, isolators, control board and bus zone protection equipment.

The new design of 132 kV outdoor oil circuit breaker, rated at 2,500 MVA (fig. 11) is now in full production and large numbers are in hand for the B.E.A. The main difference, as compared with earlier designs, is in the construction of the tanks which are of the boiler pattern and are considerably smaller in diameter so that the quantity of oil required is much reduced. Access to the moving and fixed contacts is afforded by a cover on the tank side. In other respects the breakers are generally similar to the earlier design for this rating, the modifications being confined to certain details to give an improved performance.

The range of fault-throwing switches has been extended to cover 132 kV service, and some are now in service on the Grid system. Installed where a transformer is teed-off a transmission line, a fault-throwing switch obviates the need for a local high-voltage oil circuit breaker and also eliminates pilot wires while still affording full protection to the transformer. The switch is operated by the local protective devices, and by creating an earth fault on the transmission line causes the circuit breakers at the ends of the line to trip and isolate the transformer.

One of these switches is shown in fig. 12. They are generally similar in appearance to a rotary insulating switch but are fitted with spring closing mechanism which is actuated by a remote-operated release coil. The switch is reopened by hand. These switches have been fully tested for closing against a current equivalent to 1,500 MVA at 132 kV and will carry this current for 3 seconds.

For service on carrier-current protective schemes on the 275 kV Supergrid, a line trap choke coil has been developed. It is rated to carry a normal current of 1,200 amp. and will withstand through-fault currents equivalent to 7,500 MVA at 275 kV. The coils are wound with copper strip, the turns being separated by moulded spacers and rigidly clamped between heavy insulating end plates, the inductance of the completed coil being 200 micro-henries. Trap choke coils of this design but rated at 1,600 amp., 301 kV, 7,500 MVA have been supplied to the Aluminum Company of Canada, Ltd.

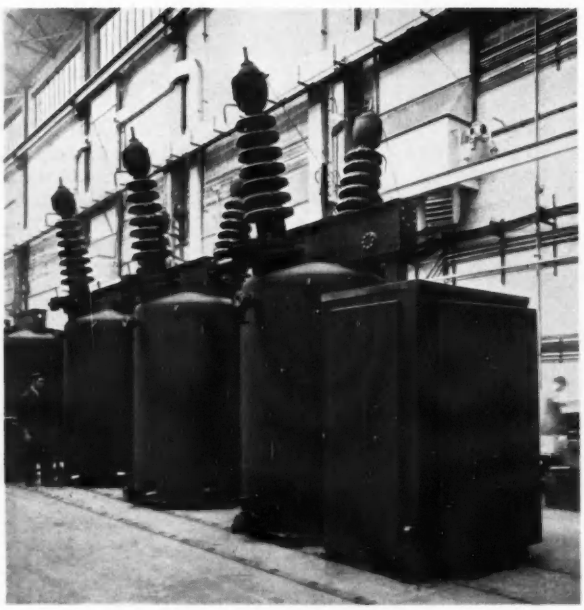

Fig. 11.—New design of 132 kV 2,500 MVA oil circuit breaker.

Continued research on the material employed in non-linear resistors for surge diverters has resulted in the production of resistors with improved characteristics. These are now fitted in all the Company's surge diverters which thus achieve lower residual voltage levels than were hitherto obtainable. The equal distribution of voltage across the units of high-voltage station type diverters through the use of resistance glaze on the porcelain containers has been proved by tests undertaken by the B.E.A. at the Insulator Testing Station at Croydon over the past two years.

Fig. 12 (*left*).—132 kV fault-throwing switch.

These tests have established that equality of voltage distribution is well maintained even under polluted atmospheric conditions.

METALCLAD SWITCHGEAR.

A large amount of heavy duty metalclad switchgear has been completed during the past year of which mention may be made of the eighteen 22 kV, 750 MVA units for Swartkops Power Station, Johannesburg, and the 33 kV units for Brisbane City Council Transport Department, nineteen of which are rated at 1,000 MVA and nine at 750 MVA. A recent contract placed by the Southern Electricity Authority of Queensland covers a further seven 33 kV, 500 MVA units, while an order for a fifteen-panel, 11 kV, 500 MVA board is in hand for the Bloemfontein Power Station, South Africa. For the Sydney County Council fifteen 33 kV units have been despatched, four rated at 1,500 MVA and the remainder at 1,000 MVA.

The heavy current 11 kV metalclad switchgear for the Nechells Power Station, Birmingham (fig. 13), to which reference was made in the progress review last year, is now in commission. It will be recalled that these breakers are designed for a current of 4,000 amps., and are rated at 1,000 MVA. Two 33 kV, 500 MVA, switchboards are in course of erection at the Middle Duffryn Power Station and Bargoed Power Station of the National Coal Board.

Much of the 33 kV, 750 MVA, metalclad switchgear which is being built for the Southern Region of British Railways has been completed and is now being erected on site. This gear is of the non-phase separated type, the development of which was recorded in last year's review, and it will be recalled that over 300 units are being supplied to the British Railways in connection with the frequency changeover in the London area.

A load breaking, fault-making oil switch has been developed and tested for ratings of 150 MVA at 6·6 kV, and 250 MVA at 11 kV. "On", "off" and "earth" positions are provided, the interlocking arrangement being such that cable

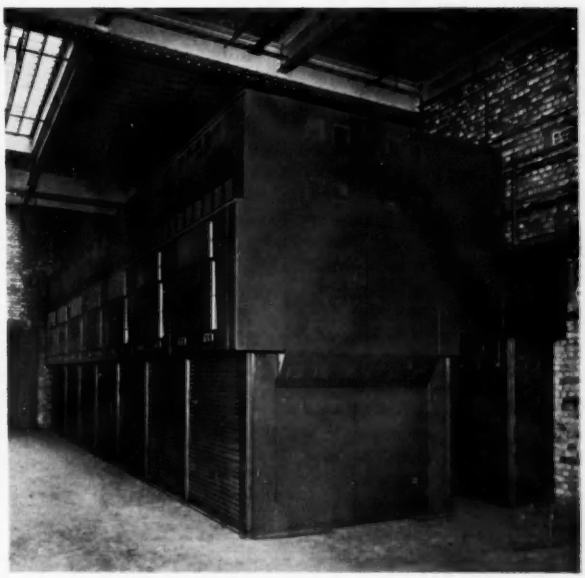

Fig. 13.—11 kV, 4,000 amp., 2,500 MVA metalclad switchgear in the Nechells Power Station, Birmingham.

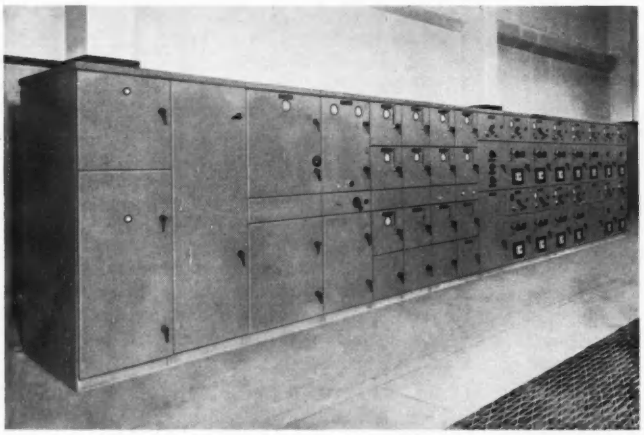

Fig. 14.—415 volt multi-tier airbreak switchgear in the circulating water pump house at Uskmouth Power Station.

testing attachments can be inserted or removed only when the switch blades are in the "earth" position. Cable testing is effected with the switch in the "off" position when the testing device is locked automatically to the casing so that it cannot be removed until the switch is returned to the "earth" position.

With the additional plant now in full operation, the output of the High Power Testing Station at Witton has been doubled, and the test area has been enlarged so that it is possible to have five circuit breakers ready for test at any one time, resulting in a considerable increase in the rate of flow of work. The maximum capacity of the plant for 3-phase tests at 6·6 and 11 kV is now 3,000 MVA, while for voltages from 19 to 66 kV it is 1,750 MVA. On single-phase tests, 1,200 MVA is available at voltages up to 152 kV. A heavy programme has been completed during the year including tests on 1,500 MVA oil circuit breakers at 22 and 33 kV and on 1,000 MVA breakers of 11, 22 and 33 kV, and a large number of development tests at 132 kV and 3,500 MVA.

AIR-BREAK SWITCHGEAR.

Multi-tier cubicle type air-break switchgear has been supplied in considerable quantity for controlling power stations auxiliaries, the two most outstanding examples being found at the Uskmouth Power Station and the Ringsend Power Station in Eire. At the Uskmouth Station all the 415 volt boards are of this type, with 15 MVA circuit breakers having current ratings of 800 and 2,000 amp. for the main supplies, fused-switches arranged in three- and four-tier form for the distribution circuits, and contactor starters in two-tier form for the motor circuits. In all, nearly 100 complete boards are involved, each comprising a combination of any or all of the types of equipment referred to above. One of these boards is shown in fig. 14.

The 380 volt equipment for the Ringsend Power Station is similar and covers six complete switchboards which individually are larger than those installed at Uskmouth.

Fig. 15.—Switchboard built from standard medium weight ironclad components.

IRONCLAD SWITCHGEAR.

The standardisation of the new ironclad switchgear is nearing completion and the following ranges are already in production.

The DW domestic range is designed for use on 250 volt, A.C. supplies and utilises double pole switches of the Mutac type with single-pole fuses and neutral connectors. This range includes switch fuses, splitter units and composite units. HRC or semi-enclosed fuses can be supplied, and each unit is available with a metal or insulated case.

For general industrial purposes the MW switchgear range covers a wide field. It is suitable for use on A.C. or D.C. circuits up to 500 volts and includes distribution fuse boards rated from 20 to 100 amp. per fuseway, switch fuses and fuse-switches from 20 to 500 amp. Distribution boards and switch fuses are fitted with HRC or semi-enclosed fuses and the fuse-switches with HRC fuses only. For use with this gear, MW switchboard components are stocked so that works engineers or contractors can build complete switchboards (fig. 15) on site from standard parts to suit their own requirements.

To meet industrial requirements where the conditions are particularly arduous and where protection against dust and moisture is important, the HW switchgear range has been introduced. This covers switch fuses ranging from 20 to 100 amp. housed in extremely robust cast iron cases. End plates and covers are fitted with gaskets and spindle bearings are bushed.

The new range of flameproof gear comprises switch fuses from 15 to 100 amp., with HRC or semi-enclosed fuses for use on supplies up to 660 volts. These can be installed as separate units or, in conjunction with a stocked range of flameproof accessories, can be built on site into distribution switchboards (fig. 16) to meet customers' requirements. This gear is covered by certificates issued by the Ministry of Fuel and Power Testing Station at Buxton for gases in groups 1, 2 and 3.

MEDIUM POWER TEST PLANT.

A medium power test plant has been brought into service at Witton Works for D.C. and A.C. short-circuit testing of switchgear for industrial, traction and general purposes. It is situated in a brick building adjoining the Mercury Arc Rectifier Works, the A.C. and D.C. supplies for testing being obtained from the large motor-generator sets in those works. Heavy current busbars feed the testing bay where short-circuit currents of 12,000 amp. 3-phase A.C. and from 20,000 to 35,000 amp. D.C. are available.

The building is divided into four sections. The first contains the necessary switchgear and current limiting reactors, to enable the appropriate A.C. or D.C. switching circuit to be set up. The second section, which is equipped with overhead monorail lifting equipment, is the test area, while the remaining two sections serve as control room and dark room respectively. Permanently mounted cathode ray and Duddell oscillographs and all the necessary measuring facilities are provided to give complete electrical records of the behaviour of the equipment under test.

Since this plant was commissioned about 12 months ago, it has been in continuous use and has proved to be an important addition to the extensive testing faculties at the Works.

HIGH VOLTAGE HRC FUSES.

Development of a range of fuses from 3·3 kV to 66 kV with equivalent breaking capacities from 150 MVA to 750 MVA is in an advanced

Fig. 16.—Flameproof switchboard built from standard components.

stage and 33 kV fuses are already being manufactured.

Used in conjunction with load breaking isolators they provide an inexpensive means of protecting and controlling electricity supplies to sparsely populated areas, especially in the early stages of development.

PROTECTIVE SCHEMES AND RELAYS.

FEEDER PROTECTION—TYPE MHS.

A standard scheme of feeder protection, using pilot wires, has been developed to satisfy a wide variety of service conditions. It is known as type MHS and is shown diagrammatically in fig. 17. Basically it operates on the opposed voltage principle and by the use of a sensitive and robust moving iron relay, together with special bias features and suitable dimensioning of components, the following performance is achieved:

1. *Low fault settings*, the standard settings being phase-to-earth 24 to 40 per cent, phase-to-phase 64 to 150 per cent; and three phase 70 per cent.
2. *High speed of operation*, the operating time being 0·04 secs. at 3 times the current setting.
3. *High degree of stability.* The scheme remains stable with through fault currents up to 60 times the rating of the line current transformers.
4. *Applicable over a wide range of pilot conditions.* The standard scheme is suitable for pilots of up to 1,000 ohms loop resistance and with a capacitance between cores of up to 4 microfarads.
5. *Only two pilot cores are required.*
6. *Pilot voltage is limited to* 95 *volts maximum* so that dry paper insulated pilot cable such as is found in telephone circuits can be used.
7. *With isolating transformers in circuit, it can be used with aerial earth wire pilot cables.*
8. *Operation is effective at both ends of the protection scheme for all types of internal fault*, irrespective of the number of ends from which the fault is fed.

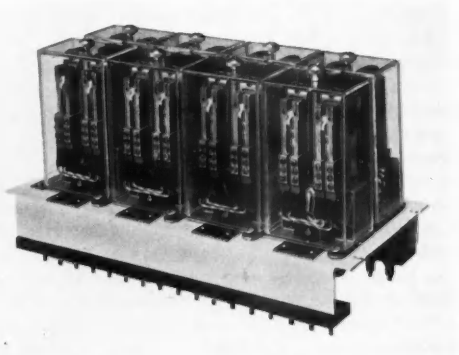

Fig. 18.—Group of eight annunciator relay units.

9. *Current transformers of low performance can be used.* For a 5-amp. current transformer a knee point voltage of only 20 volts is required.

A further development of the scheme, type MHSL, has reached an advanced stage, and is particularly suitable for use on hired G.P.O. pilots. It is suitable for pilot loop resistances up to 3,500 ohms, is equipped with pilot supervision, and complies with the G.P.O. safety requirements regarding insulation between the power apparatus and the pilots.

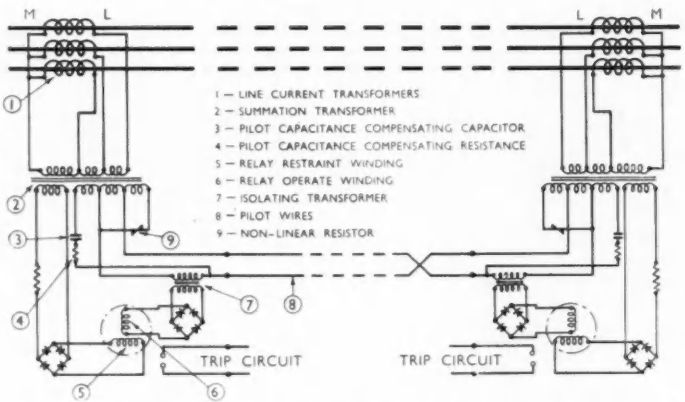

Fig. 17.—Diagrammatic arrangement of the feeder protection scheme.

ANNUNCIATOR RELAY UNIT TYPE PSM.

This unit forms an addition to the range of annunciator and alarm relays, and is considerably smaller than the type PSP unit. It is designed for use on 50 volt D.C. circuits whereas the type PSP unit is suitable for voltages up to 250 volts D.C.

The type PSM units are arranged in groups of eight (fig. 18) each unit being arranged to be individually "plugged in" to the group base, thus facilitating maintenance and replacement. Each unit has a "Perspex" cover so that visual inspection is easy. Each annunciator group is wired to terminals to which multicore cables and other external connections can be made direct. The groups for a particular application can be mounted either in a special cubicle reserved for this purpose or they can be distributed in the various cubicles of a control panel according to requirements.

This unit is being used for the alarm and fault annunciator schemes of a number of power stations and switching stations, one particular installation utilising more than 400 units. The normal facilities provided are that, when an abnormality or fault occurs, the appropriate section of the annunciator-indicator gives a flashing signal together with an audible alarm. The audible alarm can be cancelled from a central position, the flashing signal being subsequently accepted and brought to a steady illuminated indication by depressing the "accept" key on the control panel. After the information is logged the indication is cancelled either by a "reset" key or in some instances by the resetting of the initiating device.

Protective Relays for Oil Refineries.

For certain processes in oil refineries reliability of the electric power supplies is of paramount importance, and, in the event of a fault, an alternative source of supply must be introduced automatically. Furthermore, the protective scheme must be simple and comprise only robust equipment. The required performance has been achieved by a co-ordinated scheme of overcurrent and undervoltage protection using specially developed relays as follows :

(*a*) An inverse time overcurrent relay, type B, with a basic 1-second definite minimum time as compared with the standard 3-second characteristic.

(*b*) A type B/AM overcurrent relay which is a combined inverse time relay with a high set instantaneous element. These are available with a wide assortment of current ranges for both elements.

(*c*) A type B/UV undervoltage relay in which the time of relay operation decreases with decreasing voltage.

Heavy Current Test Plant.

The first section of a new heavy current test plant (fig. 19) is now in operation. This equipment provides facilities for the complete testing of protective systems under conditions similar to those experienced in service. The plant comprises a set of three single phase power transformers supplied at 11,000 volts through a three-phase induction regulator, together with the necessary making switch, control gear and loading reactors. The test area (60 ft. by 27 ft.) with control equipment is on a platform above the power plant.

Controlled currents up to 15,000 amperes at a low power factor are available and all types of internal and external fault conditions can be simulated. The point on the voltage wave at which the fault is applied and the phase relationship between the test current and the voltage supply to any relay can be pre-selected by means of the controlled switching apparatus. Built-in cathode-ray and electromagnetic oscillographs facilitate the recording of essential transient phenomena which are so important in modern high speed protective gear design.

The test plant will be used for ascertaining basic data for protective gear design, for the

Fig. 19.—Heavy current test plant for protective equipment with the control board in the foreground.

type testing of all protective equipment and for the routine testing of certain types of protective gear the performance of which cannot be established by secondary testing.

The second section of the plant, now in course of construction, will provide 3-phase currents up to 44,000 amp. using as its source of supply a 10,000 kVA generator, and will further increase the facilities for ensuring high performance of protective gear.

Saturable Core Over-current Relay.

For use in control gear for squirrel cage motors driving high inertia loads, a patented design of overcurrent relay has been developed which will carry the heavy starting current over the relatively long period taken to accelerate the motor up to speed without forfeiting proper protection during normal running.

On top of the operating plunger is an iron thimble which becomes saturated when the current exceeds a given value, as a result, increased current no longer gives rise to the normal strengthening of the magnetic pull and hence tripping is delayed. The plunger stem and piston are made of duralumin so that the weight of the moving parts is reduced and consequently risk of the plunger hovering in a mid-position is prevented. The operating time can be adjusted from zero to a maximum of about 40 seconds at 10 times full-load current, typical performance curves being shown in fig. 20.

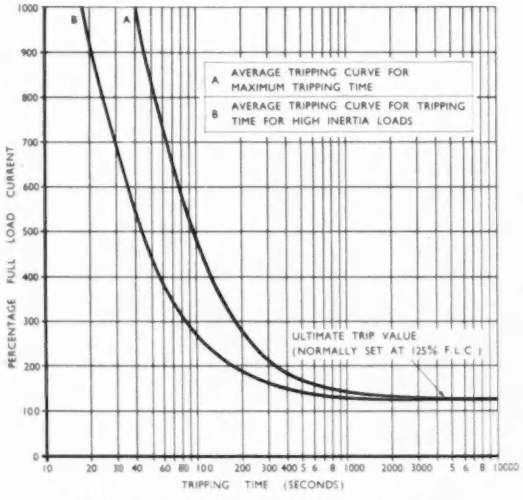
A AVERAGE TRIPPING CURVE FOR MAXIMUM TRIPPING TIME
B AVERAGE TRIPPING CURVE FOR TRIPPING TIME FOR HIGH INERTIA LOADS
ULTIMATE TRIP VALUE (NORMALLY SET AT 125% F.L.C.)
PERCENTAGE FULL LOAD CURRENT
TRIPPING TIME (SECONDS)

Fig. 20.—Performance curves of the saturable core overload trip relay.

Power Units for Carrier Frequency Protection Systems.

In order to preserve continuity of supply in carrier frequency protection systems, emergency

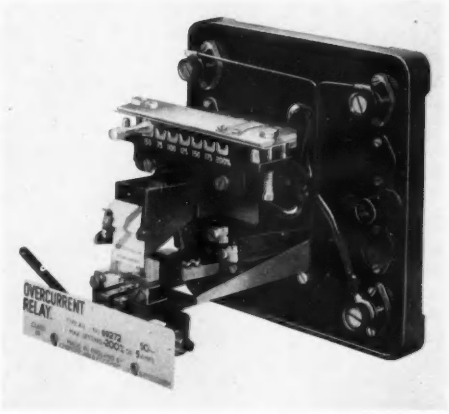

Fig. 21.—Single-pole relay, type Ax, with cover removed.

power units with associated control gear have been developed and are now in service on a number of systems.

Normally power is supplied from a small generator driven by a 2 h.p. motor which is fed from the A.C. mains. Should the A.C. supply fail, a second motor-generator set, which is fed from a battery, automatically takes over the load. A flywheel on the main set keeps it running until the emergency set is up to speed so that the power supplied to the protective system never falls below a specified minimum.

As soon as the supply from the A.C. mains is again available, the main motor-generator set automatically resumes its duty and the emergency set is cut out.

Relays, Protective and P.F. Correction.

In the last twelve months the Chamberlain & Hookham Works have added three new relays to their already extensive range. Of these, two are protective relays and the third is for automatic power factor correction.

The Ax relay (fig. 21) is an attracted armature pattern instantaneous relay suitable for overcurrent, earth fault, or circulating current differential protection. Tappings from the coil are connected to a seven-position plug-bridge which allows easy alteration of the ampere turns and hence the sensitivity of the relay. The operation indicator is

Fig. 22.—Vertical flush pattern relay, type BPF.

distinctive, showing a red diagonal stripe across a white ground, and the contacts may be arranged to open or close and to be hand-reset or self-reset. The type Ax relay is available in single, double or triple element cases arranged horizontally or vertically for flush or projecting mounting.

The type BPR relay is an induction pattern reverse power relay having a definite minimum inverse time characteristic. It is suitable for shipboard use and has sensitivities as low as 2 per cent. Usually this relay is mounted in single element cases only.

The type BPF relay (fig. 22) is a double element relay for automatic power-factor correction, and can be arranged in a horizontal or vertical case for projecting or flush mounting. One element is sensitive to kVAr in the load and has adjustable settings of 4, 12 and 20 per cent, each variable by a multiplier of 0-4, giving an overall range of 0-80 per cent. Contacts on this element are used to control the direction of rotation of the rotor in the second element. The rotor is geared to an operating cam which opens or closes a series of contacts up to 10 in number which are used to control the switching of power-factor correction capacitors. The compact arrangement of contacts makes possible a much smaller relay than has been available hitherto, and more robust construction has been obtained by the avoidance of glass-enveloped mercury switches.

OIL-FILLED CABLE.

To meet the increased demand for high-voltage cables of the oil-filled type, which have, so far been supplied for operation at 22, 33, 66, 132 and 301 kV, the manufacturing plant required for the drying and impregnation of these cables at the Eastleigh Works of Pirelli-General Cable Works has been considerably enlarged.

In fig. 23, on the right-hand side, are shown a group of five new tanks of the standard type in which the metal-sheathed cables are heated in live steam at atmospheric pressure while being evacuated internally prior to filling the insulated cores and oil ducts with degasified oil. Associated with each tank is a separate high-vacuum rotary pump, high-vacuum measurement apparatus, and oil-impregnation plant similar to that situated at ground level under the platform on the left-hand side of the photograph.

In the foreground are the two very large tanks recently installed for processing cables which will

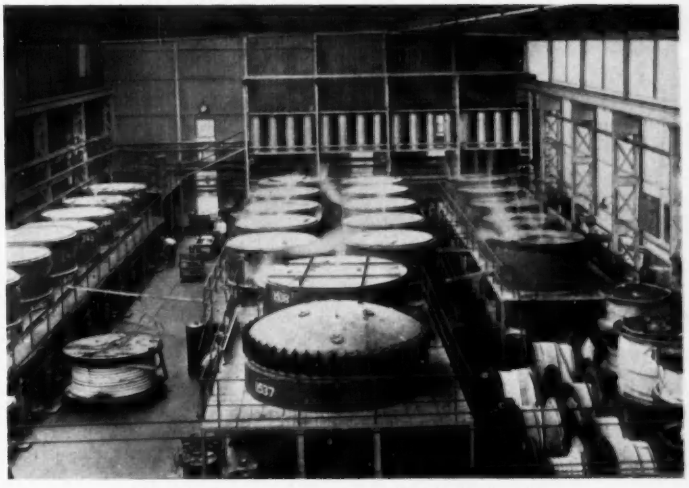

Fig. 23.—Impregnation section for oil-filled cables.

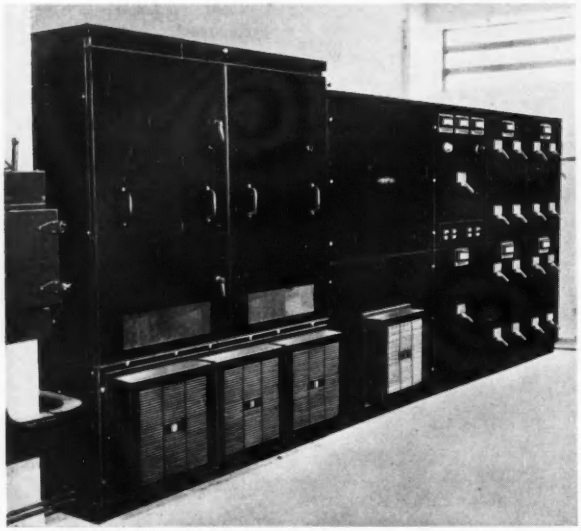

Fig. 24.—220 kW single anode rectifier and control equipment for a high-speed rotary printing press.

operate at 275 kV and upwards, the nearer one with domed lid being a steam-jacketed vacuum tank connected to a high capacity reciprocating pump for drying the core prior to metal sheathing.

In common with other cable makers, the Pirelli-General Cable Works has installed a length of single-core oil-filled 275 kV cable for field trials at Staythorpe in connection with the 275 kV Supergrid. To match the overhead line, a prototype cable having a conductor size of 0·4 sq. in. was required, but, since the transformers at present available will not fully load a cable of this size, a conductor of 70/30 brass wire has been used. This has enabled a cable to be designed having the necessary thermal, electrical and mechanical characteristics to meet the conditions of the trial installation with negligible change in conductor size and insulation from the standard 0·4 sq. in. cable. The conductor is screened and lapped with paper tapes giving a dielectric of graded construction, which is externally screened with metallised paper, and single lead sheathed. The lead alloy sheath is reinforced with bronze tapes and protected over all with anti-corrosion serving. The final overall diameter is 3·18 in.

The straight joint and two sealing ends which form part of the Pirelli-General installation have been designed in the light of experience gained with the 301 kV cables recently made for the Aluminum Company of Canada, Ltd.

During the period of test, various measurements will be taken periodically on the cable ; surge recordings will also be made.

MERCURY ARC RECTIFIERS.

Single Anode Rectifiers.

Since the introduction of single anode pumpless steel tank rectifiers, numbers of equipments of this type are being supplied for Witton-James printing press drives, and seven are now in service. An installation at the offices of the *Argus*, Cape Town, is shown in fig. 24.

Six single anode rectifiers are connected in a 3-phase bridge arrangement, giving a maximum output of approximately 325 kW at 500 volt D.C. and are supplied direct from the 3-phase L.V. supply via fault-current limiting reactors. In this way a very compact converting equipment is provided, free from oil-filled transformers and switches, eminently suited to operate in the basement of a printing office where space is usually at a premium.

The press is driven by a number of D.C. motors fed from the grid-controlled rectifier equipment and rated at 40 to 55 h.p. A two-to-one speed range is afforded by shunt control and printing is normally carried out at a speed within this range. Speed control below the base speed as well as crawling and inching are effected by grid control of the rectifier. For this purpose a patented static phase shifting network is used.* The actual output voltage control system is of the closed loop type, a fraction of the armature voltage being opposed to an adjustable stabilised reference voltage. The difference between these two voltages, after amplification, provides the power to control the phase shift network. By this means a completely consistent inch response and crawl speed is obtained, and since the relation between reference voltage and rectifier output voltage is linear, perfectly smooth acceleration is obtained by driving the reference voltage potentiometer at constant speed with a small pilot motor. The same pilot motor drives the potentiometer controlling the shunt field supply for the motors, the field potentiometer being ineffective when the reference voltage potentiometer is traversing its control range and vice versa. In this way the whole speed range of the printing press is traversed either up or down by

* "Square Wave Transformers and their Use in Static Control of Mercury Arc Rectifiers," by S. H. Dale, C. R. Dunham and E. Friedlander, *G.E.C. Journal*, Vol. XIX, No. 4, October, 1952.

the operation of a " speed-up " or " slow-down " push button.

The field supply for the motors is provided by a 6 kW, 3-phase magnetic amplifier, which can supply the fields of two to seven 50 h.p. motors. By using a simple closed loop system, the output voltage of the magnetic amplifier is made nearly independent of the load. Thus the number of motors in use, which depends upon the size of newspaper being printed, does not appreciably affect the field voltage.

Experience in service with this new system has established that the control obtained is superior to that afforded by the A.C. commutator motor and that both the average efficiency and power factor are higher. Furthermore, maintenance has been reduced to a minimum.

Multianode Rectifiers.

In the field of electric traction, orders have been received from the London Transport Executive for five 1,500 kW, 630 volt rectifier equipments for the Moorgate Substation. Because of space considerations these rectifier cylinders will be mounted on top of the main air-cooled transformers.

A further order for another 2,500 kW, 750/660 volt rectifier means that forty-nine equipments are now being supplied for the frequency changeover in the London area of the electrified system in the Southern Section of British Railways.

For the Melbourne and Metropolitan Tramways Board two 1,000 kW, 600 volt rectifiers are being supplied. These equipments embody grid control for current limitation, in order to prevent unwanted tripping of the rectifiers in the event of a heavy overload. This is achieved by the use of a hydraulic regulator coupled to the phase shifter which controls the rectifier output voltage via the grids. The regulator is inoperative until the current reaches 150 per cent of full load when the regulator, the operating coil of which is fed from a D.C. current transformer connected in series with the rectifier output, operates as a constant current controller. Hence any rise in load above 150 per cent does not result in an appreciable rise in current and the output voltage falls.

For the Hague Tramways orders have been placed for four 1,250 kW, 625 volt equipments and one 710 kW, 1,230 volt equipment, the two different voltages being explained by the fact that 575 volts is used in the centre of the city and 1,230 volts in the outskirts.

Proof of the satisfactory operation of the rectifier equipment in service on the Netherlands Railways is afforded by the repeat order recently received for two 1,224 kW, 1,530 volt equipments with electronic arc suppression gear. When this new order is completed, the total capacity of rectifier plant supplied to these railways will be 30,000 kW.

Other overseas orders include a 750 kW, 750 volt grid-controlled rectifier for the D.C.M. Chemical Works, Delhi, and two 200 kW equipments of the unit construction type for the Calico Printers' Association, Uganda.

In the home market, repeat orders have been placed by The Steel Company of Wales Ltd., and the Appleby Frodingham Steel Co., Ltd., the former covering a 1,600 kW, 400 volt equipment and the latter, two 500 kW, 230 volt equipments.

The grid-controlled rectifiers for supplying the variable speed D.C. motors driving the induced and forced draught fans at the Huncoat and Uskmouth Power Stations of the B.E.A. are now in service, the latter installation being shown in fig. 25.

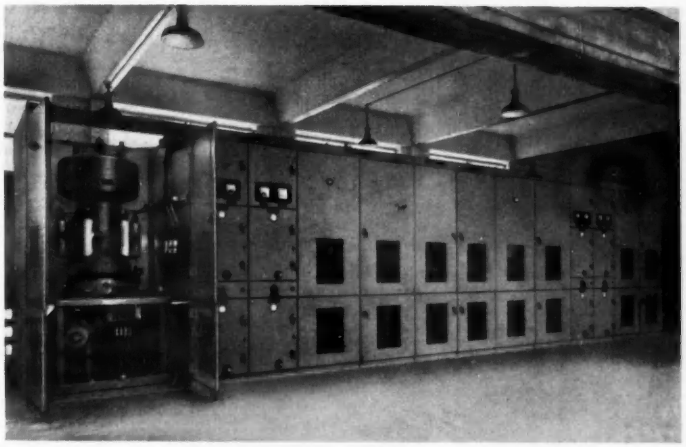

Fig. 25.—Grid-controlled rectifier equipment and control gear for the induced and forced draught fans of two of the boilers at Uskmouth Power Station.

Mining Gear

COLLIERY WINDERS.

During the period under review several orders have been received from the National Coal Board in connection with their development programme. These include two 2,100 h.p. geared A.C. winders for the new sinkings at the Lea Hall Colliery in the Cannock Chase Area in the Midlands. The equipment includes a single drum winder with an output of 280 tons per hour winding from a depth of 1,412 ft. and a double drum winder with an output of 250 tons per hour which will wind from depths of 1,032 ft., 1,420 ft. and 1,732 ft. Both equipments will be arranged for dynamic braking.

An order has been received from Garw Colliery for a 1,400 h.p., 3·3 kV geared A.C. equipment ; for Chislet Colliery two 1,200 h.p. A.C. winders are in hand. In both cases the equipment will replace steam winders.

From the South Western Division of the National Coal Board an order has been received for a 16 ft. dia. double drum winder for Glyncorrwg Colliery, which will be driven by a 1,900 h.p. A.C. motor from a 3·3 kV supply, the duty being to raise 270 tons of coal an hour from a depth of 1,800 ft. The winders at both Chislet and Glyncorrwg will embody the latest system of speed control.*

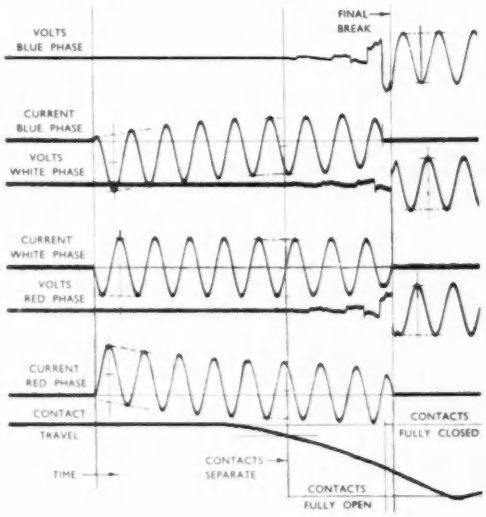

Fig. 26.—Oscillogram of the performance of an 11 kV stator reverser when breaking a current of 900 amp.

The mechanical parts of a Koepe winder using a 26 ft. dia. pulley are being manufactured for Bold Colliery, North Western Division, and an order has now been received for a rope changing winch for this winder. The winch has a single drum, 6 ft. 6 in. in diameter, and is driven by an air engine through reduction gears.

An order has also been received from the South Western Division for converting the existing single drum winder at the Mildred Shaft, Cwm Colliery, to a double drum winder for serving several levels. The mechanical parts of the existing winder were supplied in 1913 and it has been dealing mainly with the output of coal. When the reorganisation of the colliery is complete, the coal output will be handled by a 3,000 h.p. A.C. automatic winder now on order for the Margaret Shaft; the Mildred Shaft double drum winder will handle men and material only.

Development of the 11 kV stator reverser for the 3,000 h.p. fully automatic winder at Margaret Shaft has been completed and a unit successfully tested, an oscillogram of the performance of the contactors when breaking 900 amp. being shown in fig. 26. The equipment has also satisfactorily withstood the normal flash test at 28·5 kV and an impulse test of 70 kV.

The reverser is generally similar in design and appearance to the existing 3·3 kV and 6·6 kV equipments, a 3-phase contactor assembly being shown in fig. 27. It is operated by an air engine of orthodox design through an electro-pneumatic valve. Operation is quiet, smooth and positive both on opening and closing. The arc chutes are of standard design for high voltage contactors and consist of two outer sheets of arc resisting material between which are mounted

* "Speed Control of A.C. Winders," by E. Friedlander S. A. G. Emms and C. A. Maer, *G.E.C. Journal*, Vol. XX, No. 3, July, 1953.

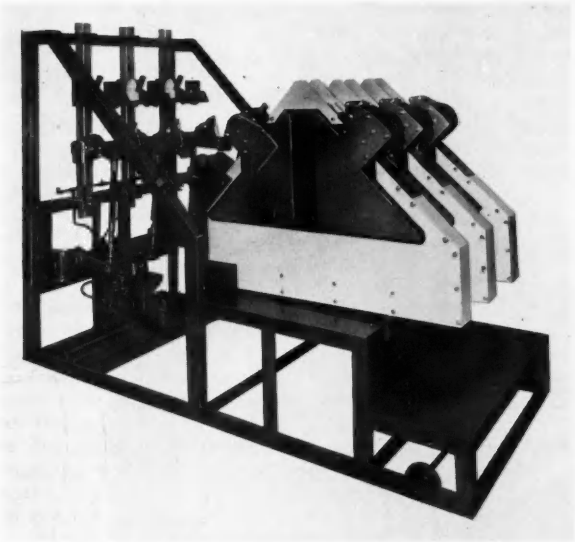

Fig. 27.—A three-phase contactor assembly for an 11 kV stator reverser with the arc chutes lowered.

spacing pieces carrying arc runners, one for each contact. Two blow-out coils are provided on each arc chute, one being connected to each of the runners in such a way that the blow outs are only inserted during arcing. This construction permits the use of a blow-out coil with a winding of reduced section and increased number of turns. In the centre of the chute are two additional plates of arc resisting material, tapering slowly from the contact end to the top opening of the chute through which the arc is forced by the blow-out flux.

Individual phase assemblies are carried on vertical steel insulated bars which are supported from the main angle structure by insulating blocks. The vertical bars reduce the tendency for dust to accumulate.

The range of liquid controllers of the weir type has been extended to cover motors up to 3,000 h.p., and a unit is now available which is capable of continuous dissipation of 1,500 h.p. when supplied with cooling water at a rate of 4 gallons per horsepower per hour. The first controller of this rating to be installed will be that for the 3,000 h.p. winder at Cwm Colliery.

Several winders are in course of erection including the two A.C. skip winders for shafts Nos. 2 and 3 at Manvers Main Colliery. The motors are rated at 1,550 h.p. and 2,250 h.p. respectively, the winders being of the bi-cylindro-conical drum type.

Other equipment now being installed includes the mechanical parts of a 24 ft. dia. pulley Koepe winder and rope changing winch for Bradford Colliery; also the mechanical parts

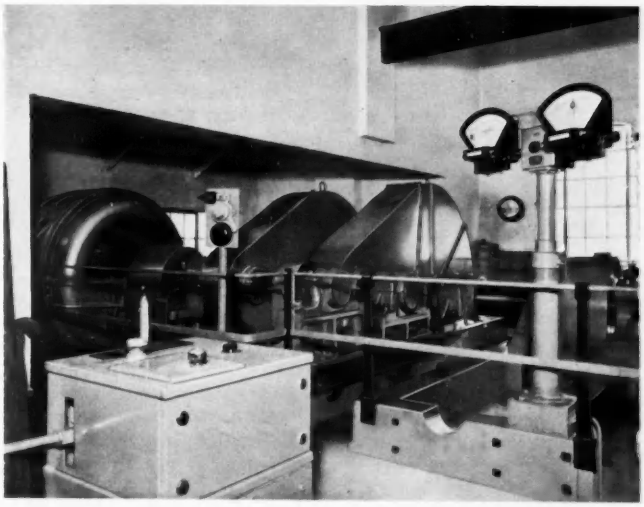

Fig. 28.—700 h.p., 3·3 kV, 365 r.p.m. A.C. haulage equipment at Pantyffynnon Colliery, South Wales.

of a double drum winder for Mardy Colliery.

It is notable that the Koepe winder installed at Bradford Colliery will probably be the first large winder of this type to be commissioned in this country. Although Koepe winders have been used for many years on the Continent, it is only in recent years that they have been seriously considered in this country. The interest they are now attracting is due to the fact that the Koepe winder is ideal for large outputs of coal from the deep levels now being considered. Winding 10 or 12 tons of coal from, say, 3,000 ft. requires a large rope, and the drum winder, as an alternative to the Koepe, would require a large drum with its consequent high moment of inertia. An advantage of the Koepe system of winding is that it is possible to design the winder for the deepest level to be encountered, and yet coal can be wound from shallow levels, initially, with a smaller rope, and as a deeper level is opened up it is only necessary to replace the main winding rope and balance rope and adjust the depth indicator. The rope tread on the Koepe pulley being made of wood or leather is easily adjusted to suit the larger rope. The development of a mine may be such that a moderate output is accepted from a certain level which will be considerably increased some years later. Such a condition can suitably be dealt with by a Koepe winder and is, in fact, the case with the 26 ft. dia. pulley Koepe winder to be installed at Bold Colliery.

MINE HAULAGE.

One of the largest slant haulages in the South Wales coalfields to be equipped with dynamic braking has recently been commissioned at Pantyffynnon Colliery, near Ammanford. It was formerly driven by a steam engine which has been replaced by a 700 h.p. geared motor operating at 3·3 kV (fig. 28). The total length of the haulage is 1,000 yards over gradients varying from 1:2·1 to 1:5·5, the maximum load comprising 11 trams with a total dead weight of 17 tons. The normal duty cycle provides for seven journeys per hour at a maximum rope speed of 12½ m.p.h. representing a total of 475 tons of coal per 8-hour shift. When used for man riding, the maximum rope speed is limited to 6¼ m.p.h.

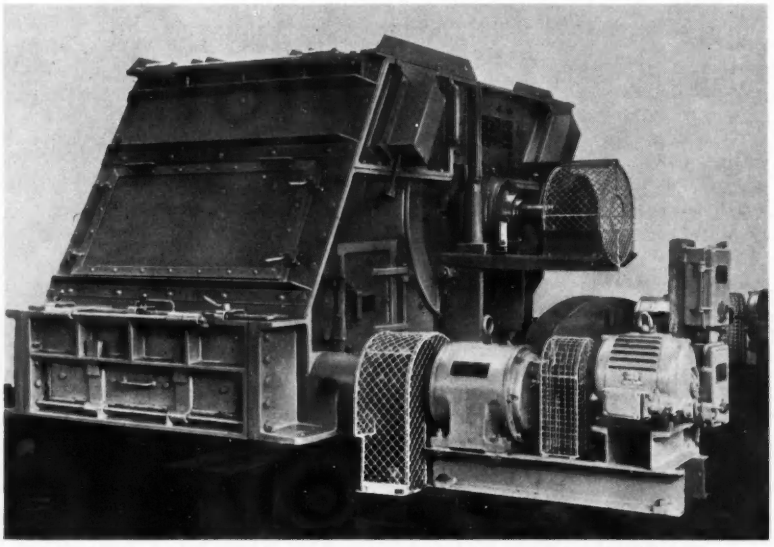

Fig. 29.—One of six special hammer mills for Appleby-Frodingham Steel Company.

"DIXIE" MOVING BREAKER PLATE HAMMER MILLS.

For the Appleby-Frodingham Steel Company, Scunthorpe, a contract is in course of execution for six special hammer mills, each weighing 18½ tons, to carry out the final crushing of iron ore for sintering (fig. 29). The final design of

the machines has been developed at Scunthorpe over the past twelve months by experiments with a modified existing unit. The duty required of each mill is to reduce iron ore from $\frac{3}{4}$ in. to $\frac{1}{4}$ in., at the rate of 120 tons per hour, and the condition of the material varies with the weather conditions from being almost bone dry to a consistency approaching that of wet clay. The problem was to produce a machine to operate with a minimum of dust nuisance when working on dry ore, and to prevent plugging up when crushing wet material.

Three existing hammer mills supplied from the United States and embodying a moving front plate were not satisfactory, as they required cleaning of built-up material two or three times in every shift. An additional moving plate travelling round two sprocket shafts was added to the rear of one of the existing mills and, after a full series of experiments and alterations, a successful arrangement was decided upon.

The six new machines are an improvement on the original prototype, in that a maximum of accessibility has been achieved which, together with special feeding and discharge features, should go a long way towards solving the age-old difficulty of treating damp and sticky materials.

LIMESTONE CRUSHING AND SCREENING PLANT.

A large limestone crushing and screening plant for Beswick's Lime Works, near Hindlow, Derbyshire, is now in process of completion. The contract comprises all the mechanical parts, including all the machinery, conveyors, bins and buildings, and so forth.

The duty of the plant is the crushing of 200 tons per hour of run-of-quarry limestone to minus 7 in. and under, and sizing the products from the crusher into three fractions.

The plant is served by 35-ton Foden side-tipping wagons, which are tipped by means of a special semi-automatic winch tipping gear into a very strongly constructed hopper 18 ft. long, which discharges to an apron feeder 5 ft. 6 in. wide between skirt plates. This, in turn, feeds down a short chute to a Sherwen conveyor feeder, about 54 in. to a cataract roll grizzly, 54 in. between cheek plates, into a 54 in. by 42 in. Blake sledger.

The undersize from the 5-roll grizzly, which has 6 in. openings, passes to a rotary screen 5 ft. dia. by 21 ft. 6 in. long, of square construction, where the minus 3 in. stone and dirt will be screened out, this stone and dirt falling on to a belt feeder, by means of which it is conveyed to an inclined belt conveyor and carried to a surge hopper of 10 tons capacity. The hopper is discharged by an apron feeder, 36 in. wide into the side tipping rail wagons.

The crushed product from the Blake sledger will be discharged on to a reciprocating plate feeder, 30 in. wide, and fed on to a 36 in. inclined belt conveyor which will carry it to the 36 in. main conveyor by which it will be transported to the screen house and crushed stone bins. This conveyor is some 380 ft. long, with a rise of some 86 ft., and discharges into a 5 ft. dia. by 40 ft. long rotary screen mounted above the bins.

The rotary screen is equipped with three sections of screen plates, the first section having 3 in. dia. holes, the second section 5 in. dia. holes, and the third section 7 in. dia. holes and being partly blank.

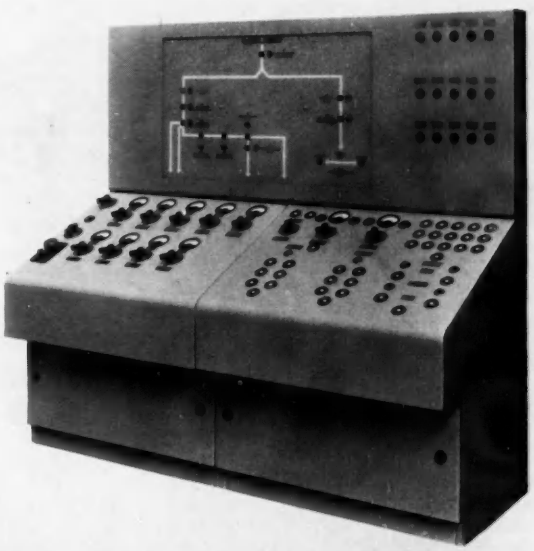

Fig. 30.—Railway sidings control desk at Penrice Quarry of I.C.I. Alkali (Australia) Pty., Ltd.

The storage bins below this screen are grouped together and give a total bin capacity of about 850 tons, and are constructed with three compartments formed with sloping bottoms and discharged by means of tipping gates and apron feeders, which are inclined and provided with

2-way discharge chutes fitted with flopper gates so that they can deliver to either side of the plant. The chute controls, and also the push button starters for these feeders, are arranged so that they can be operated by one man from the ground.

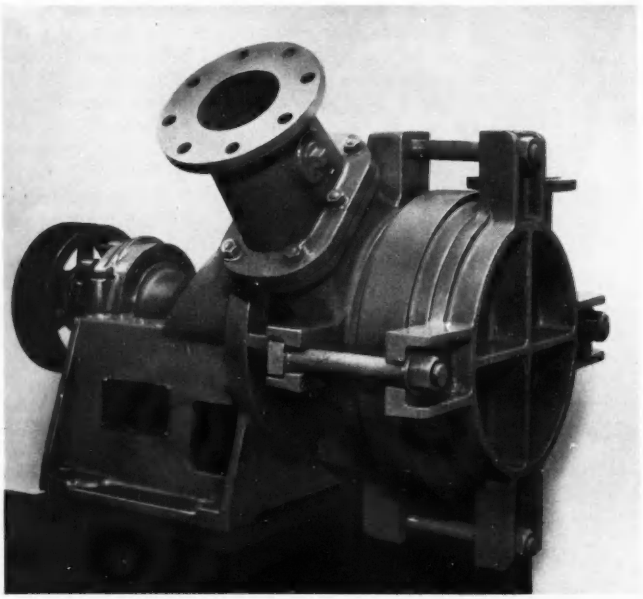

Fig. 31.—Delivery end of type R sand and slurry pump.

The plant in general is designed for the most economical operation; the starters for all the different machines are grouped on a platform in the Main Crusher House, with local controls as required.

The rotary screens are carried by supporting rollers which are rubber-tyred to ensure quiet running. The plant foundations are well on the way to completion and the Crusher House building is in the course of erection. The total motor power installed for driving the various machines is 388 h.p.; the largest motor, which is that required for the Blake sledger, is of 170 h.p. The crusher house is served by a 20-ton overhead hand-operated travelling crane.

It is expected that the plant will go into operation in the early spring of 1954.

Electrical equipment is now being installed at Penrice Quarry of I.C.I. Alkali (Australia) Pty., Ltd., for controlling limestone ore handling plant which includes conveyors, feeders, screens, crushers, tippers, winches, fans, storm water pumps and so forth. The motors, the largest of which is rated at 225 h.p. and drives the jaw crusher, are controlled in a fixed sequence as dictated by the flow of the material.

Should any drive fail, all the preceding motor drives are automatically shut down so that limestone cannot pile up. Any one of a number of sequences can be selected depending upon requirements such as stock-piling, loading, etc. All the control gear is housed in multi-tier cubicles and is remote-operated from control desks (fig. 30) on which flow-diagrams are mounted. These together with indicating lamps show the operation of all the various drives. Audible warnings are sounded when the plant is starting up.

R TYPE PUMPS.

Recently supplied to the Australian Aluminium Production Commission were six of the latest R type slurry pumps, manufactured at Fraser & Chalmers under agreement with the Morris Machine Works of America (fig. 31).

This pump, which is of the centrifugal, horizontal type, with overhung impeller, has its suction branch on the drive side of the impeller, hence the gland packing is subject only to suction or positive head pressures.

In this latest and most advanced design of slurry pump, the suction and delivery branches can be swivelled vertically to suit any suction and discharge connection. The elimination of all troublesome internal studs and bolts by the use of only four clamping bolts for securing the shell, end cover and liner, is an important feature both for maintenance and trouble-free operation.

The arduous duty for which two of these pumps were required necessitated the use of manganese steel for all wearing parts.

COAL PREPARATION PLANT.

During the year under review five Chance washery plants were commissioned, the largest of these being capable of handling 465 tons of coal an hour for the National Coal Board's Mansfield Colliery in Nottinghamshire (fig. 32). Of the others, three were commissioned in

South Africa, namely, Schoongezicht, 335 tons an hour; Cornelia, 145 tons an hour; Vierfontein, 330 tons an hour and one in India, at Jamadoba, which is handling 300 tons an hour.

Orders received for coal preparation plants include one for Corrimal in New South Wales, Australia, which will be capable of handling 200 tons an hour, and four for the National Coal Board in the United Kingdom; these will be for Newlands, Cwm and Cynheidre in the South Western Division, and Horden in the North Eastern Division.

For Cwm colliery in the No. 3 (Rhondda) area the plant will deal with two grades of coal and will comprise two separate units, each capable of handling 200 tons of coal an hour. Each section will include a Chance washer and the necessary froth flotation and water clarification units.

At Horden Colliery, in the Durham division of the National Coal Board, the contract calls for provision of plant to deal with 170 tons an hour and will consist of a primary raw coal screen, Chance sand flotation plant including a 10 ft. dia. cone, clean coal sizing and screening plant and general loading equipment.

Plant now being commissioned at home and overseas includes one for the Natal Exploration Co., Ltd., of South Africa, which will handle 230 tons an hour, and a similar installation for Nantgarw Colliery, South Wales, with a capacity of 350 tons an hour. At the latter plant provision is being made to extend the equipment to deal with 700 tons an hour as the colliery is developed. The plant will combine both the Chance and froth flotation processes, the latter having a capacity of 60 tons an hour of minus $\frac{1}{16}$ in. coal.

The froth flotation plant is the outcome of many years intensive development work, in the course of which a pilot plant was erected in a colliery in South Wales. A high separating efficiency is attained and all coal sizes up to $\frac{1}{16}$ in. can be successfully cleaned. Basically, the plant consists of a bank of cells in series, each having an agitation box with frothing chamber attached; each box has its own cruciform impeller driven by a vertical spindle motor. The overflow from the agitation box to the frothing chamber is controlled by a weir and once the coal has risen to the surface of the frothing chamber the residue passes to the agitation box and so on to the end of the unit.

Fig. 32.—Mansfield Colliery, Nottinghamshire, where there is installed a Chance Washery to handle 465 tons of coal an hour.

Materials Handling

An order has been received for iron ore handling plant to form part of the Seraphim extension of the Appleby-Frodingham Steel Co., Ltd. Conveyors are also being supplied for the sinter plant for the same extension to the order of Head, Wrightson & Co., Ltd., the total length of these being no less than 3¼ miles. In addition, a 60-ton capacity Fraser & Chalmers Marshall side-discharging wagon tippler is included in the contract to the order of Ross Engineers, Ltd. This design has been developed to meet the need of steelworks for a robust high capacity tippler.

Fig. 33.—The Robins Messiter coal blending plant at John Summers & Sons, Ltd.—the first coal-blending plant of its kind in the world.

Two further similar tipplers are in course of manufacture to the order of Ross Engineers Ltd. for the extensions at the South Durham Iron and Steel Works at West Hartlepool.

The coal blending and handling plant supplied to John Summers & Sons, Ltd., at Shotton, Flint, to the order of Simon Carves, Ltd., which was recently opened by H.R.H. The Duke of Edinburgh, is illustrated in fig. 33. The plant is now in commercial operation with satisfactory results and a further wing tripper has been ordered to increase the capacity of the plant.

At Aviles, Northern Spain, a complete new steelworks is in course of construction by Empresa Nacional Siderurgica S.A., which when completed will be the largest in Spain. The Erith Works are supplying, to the order of Head, Wrightson & Co., Ltd., the iron ore preparation and blending plant comprising crushing and primary screening equipment, from which the ore is conveyed to the blending plant equipped with two wing trippers and two Robins Messiter blending machines. After blending, the ore passes through the secondary screening station and from there is conveyed to the furnace bins.

In the last progress report* reference was made to a large iron ore preparation plant on order for Kapitalna Iron Works, Zenica, Yugoslavia. This plant is now in course of erection and an order has been received for extensions comprising conveyors for handling ore and sinter to the third blast furnace.

Other orders received include an extension to the coal handling plant at the Hardingstone Generating Station of the British Electricity Authority at Northampton; a coke handling plant for United Coke & Chemicals Co., Ltd., at Orgreaves, Sheffield, and a coal handling plant for the phurnacite plant of the National Coal Board at Aberaman, South Wales. This plant

* "Mining Gear," *G.E.C. Journal*, January, 1953.

includes a wagon tippler of 35 tons gross capacity with an adjustable side supporting bolster enabling it to handle all sizes of wagons in common use at the present time; the machine complies fully with the requirements of British Railways and the Railway Clearing House. It should be noted that the present railway regulations give two different heights for the side bolster beam, dependent upon the range of wagons being handled. Thus for wagons from 6 ft. 6 in. to 8 ft. 6 in. high above rail level, one height is specified, while for wagons within the range 8 ft. to 10 ft. 6 in. a different height is required. The difference between the two heights is 1 ft. which is the range of movement available. This adjustable side supporting bolster is patented and the machine is believed to be the only one capable of handling wagons of all sizes with a single tippler. The mechanism making this feature possible is illustrated in fig. 34.

Of particular interest, as being outside the normal run of such equipment, is a tea blending plant under construction for Typhoo Tea, Ltd., which will be required to handle 25,000 lb. of tea an hour. The plant is a duplicate of one installed in 1934.

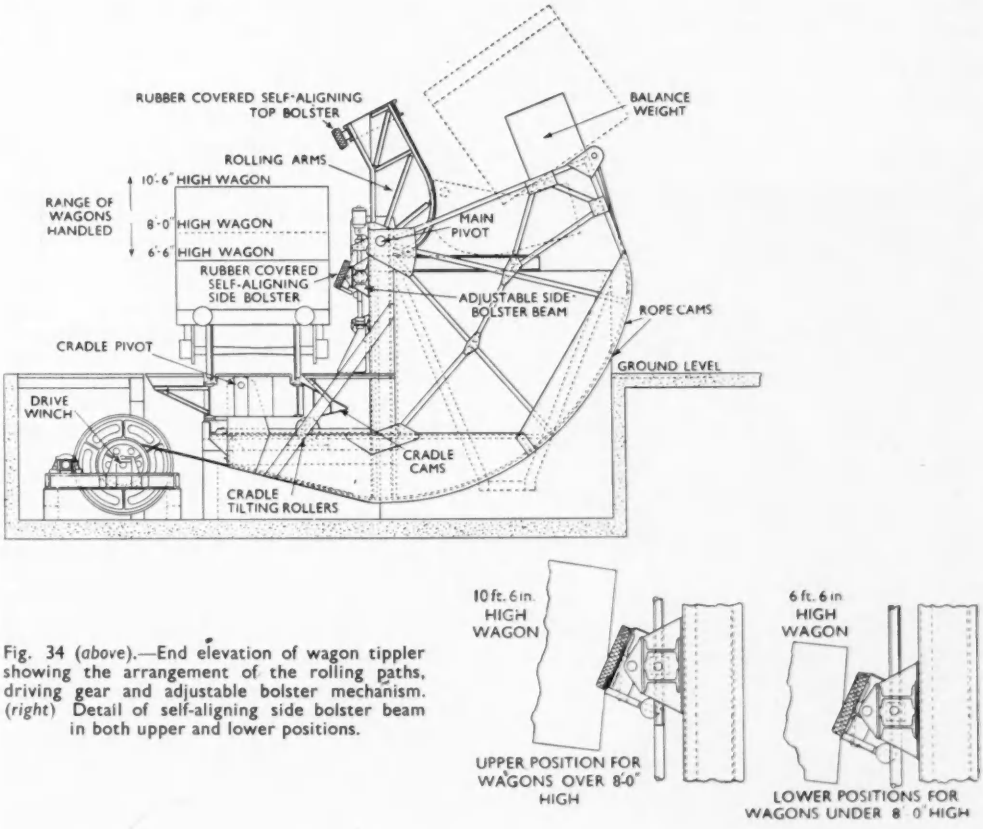

Fig. 34 (*above*).—End elevation of wagon tippler showing the arrangement of the rolling paths, driving gear and adjustable bolster mechanism. (*right*) Detail of self-aligning side bolster beam in both upper and lower positions.

Rolling Mills

The successful operation of the two 2-stand temper mills at the Trostre Works of the Steel Company of Wales, which formed the subject of an article in this Journal* has resulted in a new contract being placed for the electrical equipment for two further temper mills to be installed in the Velindre Works, near Swansea.

These mills are 42 inches wide, operating at strip speeds up to 4,000 ft. per min. and the electrical equipment will be generally similar to that installed in the Trostre Works. Each stand will be driven by a 1,000 h.p. 600 volt motor running at 700/950 r.p.m., the uncoiler and coiler motors are each rated at 300 h.p. and those for the top and bottom tension rolls at 500 h.p. and 250 h.p. respectively. Power for the mill will be provided by a 5-machine motor-generator set and full use will be made of control exciters.

Fig. 35.—A direct current mill type motor, series M, with the top half of the shell swung open.

Also for the Steel Company of Wales a further 114 mill type motors ranging from 7½ h.p. to 200 h.p. and totalling over 7,500 h.p are being supplied in connection with the new development scheme.

At the Whitehead Iron and Steel Co., Ltd., a 24-inch skin pass mill has been commissioned. The stand motor is rated at 200 h.p. and the coiler motor at 150 h.p., the mill being Ward-Leonard controlled. Constant tension is preserved by the cascade exciter system of control which provides accurate compensation for coil build up.

Three fully automatic drawbenches, one of 300,000 lb. and two of 100,000 lb. capacity each, are now in operation at the Kirkby Works of I.C.I. For the larger drawbench the main driving motor is rated at 1,000 h.p. while the motors for the two smaller drawbenches are each rated at 450 h.p. Grid-controlled mercury arc rectifiers provide the power for these machines, the speeds of which are automatically controlled. The auxiliary motors, which range from 1 to 65 h.p. are supplied from a tertiary winding on the main rectifier transformer, each drawbench being supervised from its own control desk.

A similar equipment of 100,000 lb. capacity has also been supplied to Metal Manufacturers of Australia, Pty., Ltd.

A new range of mill type motors, series M, is now in production. These machines are available in eleven frame sizes with outputs ranging from 5 h.p. to 200 h.p., and comply fully with the dimensions and ratings standardised by the American Association of Iron and Steel Electrical Engineers, Standard No. 1, dated September, 1947. The motors, one of which is shown in fig. 35, are specially designed for quick starting and stopping and are fitted with fans mounted on the armature shaft to circulate the air through the core ducts and between the field coils. Machines are also available in the force-ventilated form, which permits the nominal one-hour rating to be maintained continuously. The construction is particularly robust to withstand the severity of service encountered in auxiliary drives in steelworks.

* "The Temper Mill Drives at the Trostre Works of the Steel Company of Wales," by J. P. HUGGARD and S. A. G. EMMS, *G.E.C. Journal*, Vol. XX, No. 3, July, 1953.

Industrial and General Electrification

MOTORS.

A range of totally-enclosed fan-cooled A.C. motors which comply with the standard dimensions as given in British Draft Specification CN(ELE)6814 is in production and covers outputs as listed below :

Output h.p.	Synchronous speed at 50 cycles r.p.m.
1½ to 25	3,000
1 to 20	1,500
¾ to 15	1,000
½ to 10	750

The machines are mechanically interchangeable with those of other manufacturers and their performance is in accordance with British Standard No. 168 for class A insulation.

Motors of the flange-mounting type are also being manufactured to standard dimensions.

OIL INDUSTRY.

Orders continue to be received from the Shell Petroleum Co., Ltd., for large numbers of motors for driving oil well pumps, the latest to be placed covering over 250 machines. As these motors may remain unattended for weeks on end, their control has to be fully automatic, and special control gear has been designed for this service. It is available in three sizes: 16/30 h.p., 31/50 h.p. and 51/75 h.p. and is suitable for service on 400/460 volt, 3-phase, 60-cycle supplies.

The control unit (fig. 36), arranged for pole or wall mounting, comprises a combined circuit breaker and contactor starter, both of which are oil-immersed and contained in a common tank. The circuit breaker is hand-operated and fitted with overcurrent trips, its principal function being to afford protection against current surges due to lightning and to clear earth or short circuit faults. Repeated tests have established that the breaker will clear 5,000 amp. at 440 volts, 60 cycles, 0·4 power factor in approximately one cycle. A " hand-off-auto " control switch is provided, in addition to local " start " and " stop " push buttons. As the wells are spaced at about 200 metre intervals, several motors are supplied from one transformer. Starting is initiated by two time switches, one of which starts and stops the motors at predetermined intervals of time in order to allow the oil to collect in the wells, while the other ensures that starting is staggered and thus prevents an undue voltage drop which would occur if a number of motors was started simultaneously.

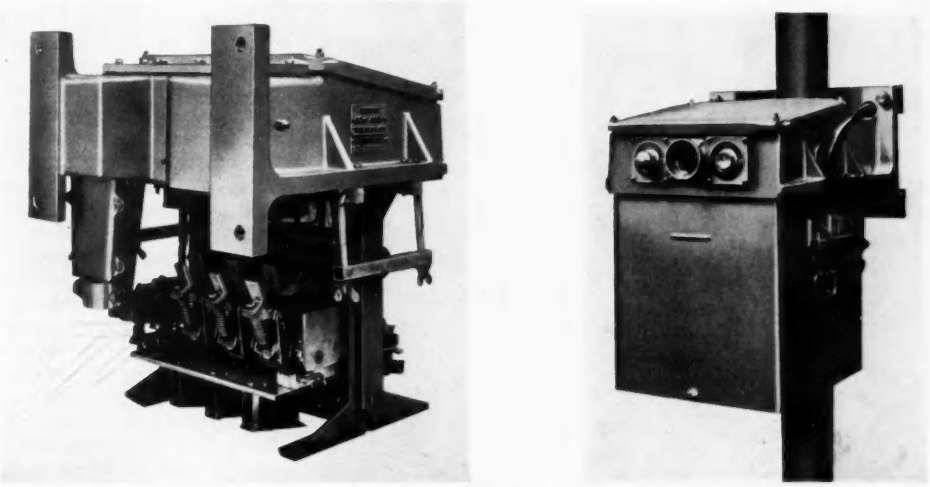

Fig. 36.—Interior and exterior views of a combined circuit breaker and contactor starter for the automatic control of oil well motors.

ELECTRIC MAGNETS.

In an earlier review of progress* attention was called to a magnetic sweep for clearing ferrous scrap from roads and runways. This was a hand-operated unit and was the forerunner of the larger equipment (fig. 37) now being produced for service on roads and airport runways. The equipment is towed by a motor vehicle and comprises magnets providing an effective sweep of 6 ft., with the associated batteries and push-button controls. The air gap between the road and the magnets can be varied up to a maximum of 4 inches by means of hand wheels. The normal air gap is 3 inches, the rate of towing then being 5 m.p.h. At reduced air gaps the towing speed can be increased up to 10 m.p.h.

A similar equipment is now being built in which power is derived from a 3 h.p. petrol engine driven generator mounted above the magnet.

Orders for lifting magnets have been well maintained and several are now in service at Montreal Pier for loading scrap iron for shipping to this country. It is interesting to record that within fourteen days of the order being received for two 64 in. magnets, they were in service in Canada, and within three weeks of the date of despatch they had handled some 2,500 tons of scrap.

FANS.

The design and tooling for quantity production of a new 60 in. sweep, capacitor type ceiling fan has been completed. The new fan (fig. 38), to be known as the "Everest", has a saucer-shaped body with the condenser readily accessible, mounted in a stirrup on top of the motor, and covered by a moulded canopy. The three frosted aluminium blades are recessed into the motor and secured by concealed fixing screws, thus preserving the smooth outline of the fan body which is finished in white with pale-blue relief. The rigid construction of the rotor, together with the bearing bracket arrangement employed, ensures concentricity of the air gap and uniform rotor resistance essential to high efficiency.

Fig. 38.—60 in. "Everest" ceiling fan.

Development of the new 12 in. and 16 in. table fans has also been completed and large scale production is due to begin in the near future. These two new designs follow closely the general outline of the 8 in. and 10 in. fans mentioned in previous reviews and will be available in both fixed and oscillating patterns. The 12 in., as with the two smaller sizes, employs rubber blades, thus eliminating the need for a guard; owing to the higher peripheral speed and increased weight, the 16 in. fans are fitted with metal blades and a protective guard. In the case of the oscillating pattern fans, the entire gear mechanism and linkage is totally enclosed and a friction clutch is incorporated in the oscillation drive. The complete range of table fans is shown in fig. 39.

Fig. 37.—A 6 ft. magnetic sweep at London Airport.

* "Magnetic Sweeps for Roads and Airports," *G.E.C. Journal*, Vol. XVIII, No. 1, p. 40, January 1951.

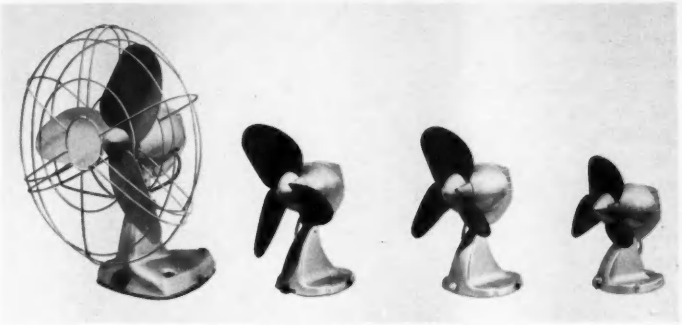

Fig. 39.—New range of desk fans.

MOBILE POWER RECTIFIER.

The Fan and Small Motor Department, which is also responsible for selenium rectifiers, has developed a mobile power rectifier equipment (fig. 40) to provide D.C. power at 28 volts for the maintenance and testing of aircraft while on the gound and also provides adequate power for starting jet engines and diesel engines for marine or transport use. It has a continuous output rating of 1,000 amp. at 28 volts and operates from a 3-phase, 50/60 cycle supply having a voltage in either the 200/240 or the 400/480 voltage range. The equipment is mounted on a two-wheel trailer and is equally suitable for indoor and outdoor use. A third retractable wheel is fitted to allow easy hand manoeuvring; a parking brake is also provided. A towing eye conforming to the Inter-Service Standard is fitted to permit its being towed behind a suitable vehicle. The switchgear and metering arrangements are shock mounted and the equipment is capable of being towed at normal speeds on good roads, or at 5 to 10 miles an hour (8-16 km an hour) over bad roads.

PRINTING PRESS EQUIPMENT.

Rotary Press Drives.

The use of conventional D.C. motors in conjunction with a controlled rectifier equipment, to provide the wide speed range and other functions required from a high-speed rotary press drive, is now well established as an alternative to the A.C. motor drive. Such drives have been supplied to the *Argus*, Cape Town, *Politiken*, Copenhagen, *Berlingske Tidende*, Copenhagen, the *Sydney Morning Herald*, the *Melbourne Herald*, and the *Evening Standard*, London. Those in Cape Town and Copenhagen have been in operation for several months and have given very satisfactory service. Further equipments are either in course of erection or production for offices at home and overseas. A description of the rectifier equipment is given in the section covering mercury arc rectifiers.

In the 'Unit' motor drive arrangement, a number of similar compound D.C. machines, one to each printing unit or folder, and having a rating of 40-55 h.p., are mechanically connected either by direct coupling using double shaft extension, as in the coaxial layout, or by conventional chain drive. The motor compounding, together with the use of the Witton-James, Ltd. interpole paralleling circuits, ensure that the machines share load very closely over a speed range of more than 40 : 1. Fig. 41 shows part of the coaxial layout of the driving motors for a 5-unit press at the *Politiken* Office, Copenhagen. Rectifier equipments are also in production for use with 'group' drives, wherein one larger D.C. motor drives the complete press.

The rectifier, with its associated circuits, and the switchgear are housed in sheet steel cubicles. Adequate access for maintenance is provided by doors at the rear of each cubicle. The selection of

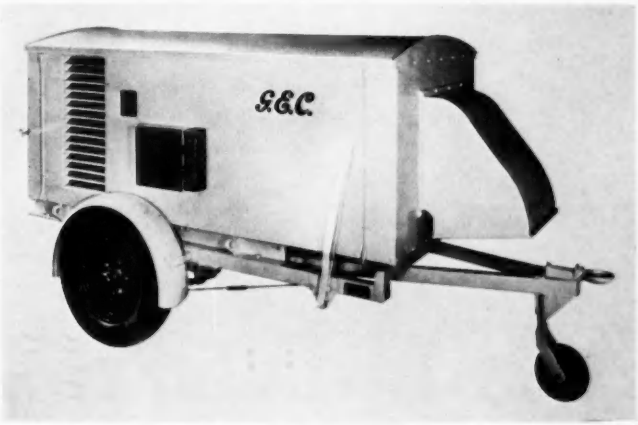

Fig. 40.—Mobile power rectifier.

motors, unit and reelstand push-button boxes, web break detectors and so forth, to meet the desired press combinations, is achieved by rotary three-way changeover switches each operated from a handle on the front of the cubicle. The switchgear cubicles also house armature and field supply voltmeters, individual motor ammeters, an illuminated press combination indicator and test push buttons.

Routine testing of the complete rectifier and switchgear circuits can be carried out at the cubicles without the necessity for running the press. Smooth acceleration over the full speed range is a characteristic feature of the equipment and experience has confirmed that this is of considerable assistance in maintaining registration in colour printing work.

Reelstand Equipment.

A further improvement in the technique of splicing a new reel to the web from an expiring reel, while the press is at speed, has been effected by the introduction of an independent electronically controlled reel motor drive, in place of a mechanical drive taken from the press itself. A description of this circuit is given under the section, "Electronic Machine Control."

Witton-James-Wood "Autopasters" incorporating this feature have been in operation, with most successful results, in the offices of the *Berlingske Tidende*, Copenhagen, and the *Evening Standard*, London. Fig. 42 shows the "Autopaster" reelstands at the Copenhagen office. The reel driving motor and associated tacho-generator are mounted on an offset bracket towards the top of each reelstand. The press tacho-generator for each reelstand is mounted on the press sub-structure and is driven by a gear or chain drive from the main press shaft. Using this electrically controlled reel drive, with either manual or completely automatic operation of the "Autopaster" sequence, continuous splicing with paper speeds of the order of 1,450 ft. per minute is being obtained.

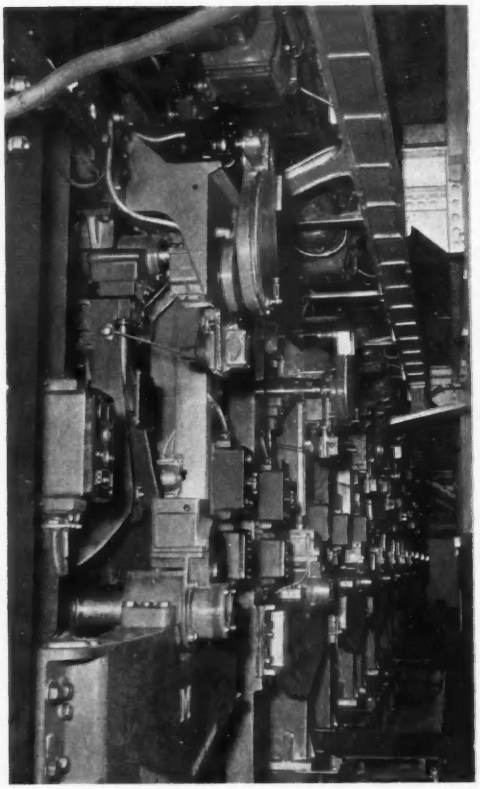

Fig. 42.—"Autopaster" reelstands incorporating electronic reel drive equipment.

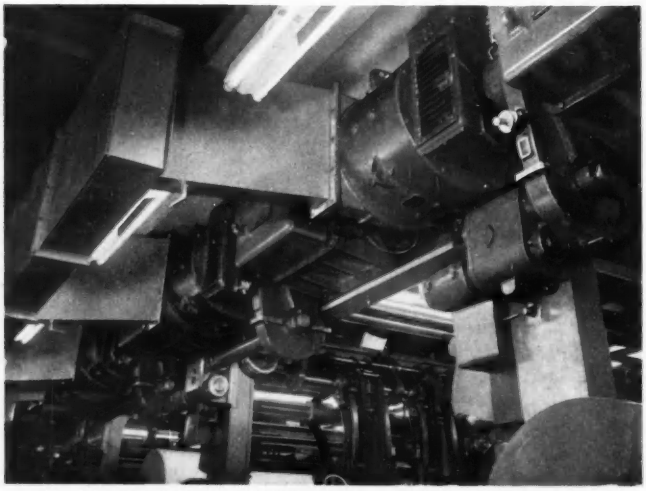

Fig. 41.—Coaxial layout of 50 h.p. motors in the 5-unit press drive at the *Politiken* newspaper office, Copenhagen.

Transport: Land, Sea and Air

TRACTION.

The electrification of the Manchester-Sheffield-Wath line of British Railways is now proceeding and it is anticipated that it will be in service during the summer of 1954. It will be recalled that the G.E.C. is supplying all the electrical equipment for the eight multiple train-units, each of which consists of a motor coach, a trailer coach and a driving trailer coach. Up to three such units may be run as a train.

Power is supplied from a 1,500 volt overhead line; but because of the special service conditions, including regenerative locomotives operating heavy freight trains, the equipments are designed for the wide voltage range of 750 to 1,800 volts. Each motor coach is powered by four motors with hourly ratings of 185 h.p. on full field and 210 h.p. on weak field. Each pair of motors is permanently connected in series, the two motor groups being arranged for series/parallel control with the usual bridge transition. The main control is by means of electro-pneumatic contactors and reversers of standard design, power for the control circuits, lighting and other L.V. requirements being supplied at 52 volts by an auxiliary motor-generator set in conjunction with a floating battery.

Apart from the collector gear on the roof and the master control equipment in the driver's cab of the motor coach and driving trailer coach of each train unit, the control equipment is mounted on the underframe. One of the under-car cases with covers removed is shown in fig. 43, while fig. 44 shows the arrangement of the master controller.

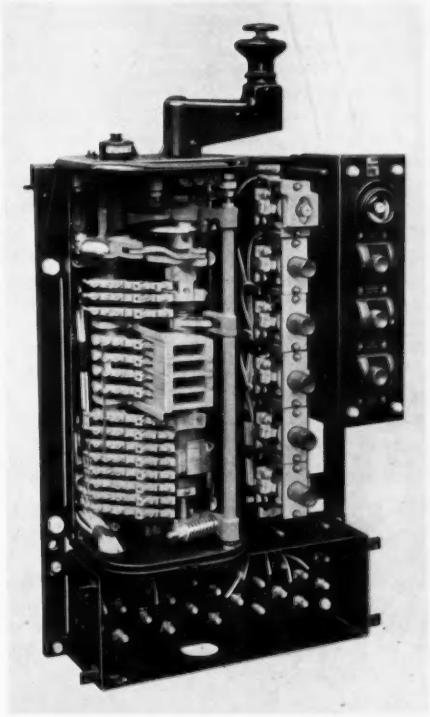

Fig. 44.—Interior of the master controller for the Manchester-Sheffield-Wath motor coaches.

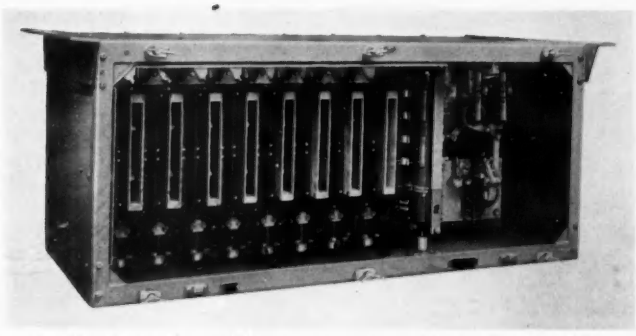

Fig. 43.—Front of one of the apparatus cases, with cover removed, for the Manchester-Sheffield-Wath motor coaches.

A recent contract from British Railways covers fifteen sets of power equipment for diesel-electric shunting locomotives. Each comprises a 350 h.p. Blackstone diesel engine direct coupled to a generator which supplies power to two axle-hung, double-reduction geared traction motors. Auxiliary power and traction motor ventilation are provided by a small generator and fan respectively, each mounted on the main generator frame

and driven by belts from the generator shaft.

The locomotives are of the three-axle rigid frame type, the outer axles being motored and coupled to the centre axle by side rods to secure maximum adhesion.

Control equipment is of the simplest nature possible, and is designed to prevent automatically any risk of overloading the diesel engine under the wide variation of locomotive speed and load. Off-load selective series-parallel control of the motors is provided. For the type of duty involved, its use enables a substantial reduction to be made in the size of the generator as compared with a scheme in which the motors are permanently connected in parallel.

A repeat order for the electrical equipment for three trolley buses has been received from Tranvia Electrico de Pontevedra, Spain. The equipment will be of the standard non-regenerative type, the motors being rated at 95 h.p., 500 volts on the one-hour basis. The control equipment is arranged for cab mounting, the master controller being of the butt contact type. Rheostatic braking is provided, utilising the G.E.C. patented scheme, type I.R., of which a brief description was given in last year's review of progress.

INTERLOCKING CONTROL PANEL FOR TORONTO RAPID TRANSIT SUBWAY.

The control of railway signal interlockings from a miniature track diagram on a control panel is now an accepted practice.

Recent developments in the construction of these panels have included improved indications and operating key arrangements which ease the work of the operator and make for increased overall efficiency.

The Siemens and General Electric Railway Signal Company has recently manufactured signalling equipment for the first subway in Canada, operating along Yonge Street from Union to Eglinton, which includes two panels incorporating these new developments.

Fig. 46.—Type CU point contactor unit for use with motor-operated point machines.

The principle of guided light through "Perspex" is used to permit two or three colours to be displayed in the same indicator aperture, operation being by means of multiple and two-position keys, the whole being mounted on a panel of "Warerite" into which is moulded the track diagram. The background is a pleasant shade of greenweave and the whole panel is recessed into a rolled steel framework finished

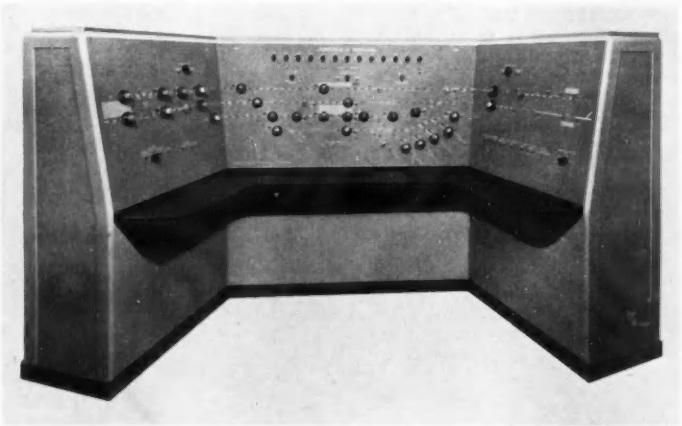

Fig. 45.—Interlocking control panel for the Toronto Rapid Transit Subway.

in stoved cream. Fig. 45 illustrates the panel for Davisville and Eglinton.

The route is set up by operating the appropriate switches. While the machines on the track are operating, the point indications on the panel are shown flashing red, but when the points are correctly in position the whole route becomes a steady white " line of light ". Occupation of the track by a train causes the indication to change to red. Signals are repeated in their appropriate colours as red, yellow or green.

TYPE CU POINT CONTACTOR UNIT.

The Siemens and General Electric Railway Signal Company has designed the Type CU point contactor as a plug-in unit for use in point circuits where their Type HA or Type HB point machines are to be controlled (fig. 46). It incorporates an overload device which is reliable in operation and yet is almost instantaneously reset. In appearance, and construction of housing and mounting base, the type CU contactor is similar to the range of S.G.E. plug-in relays, differing only in width ; hence, when plugged in alongside other relay equipment there is no break in the harmonious appearance of the whole. Standard operating voltages of 12, 24 and 110 volts D.C. and 110 volts, 50 cycles have been adopted, the power consumption of the contactor coils being of the order of 5 watts.

The unit comprises two double pole contactors, mechanically interlocked, and each fitted with a proving contact. The power contacts are fitted with magnetic arc blow-outs and are capable of breaking inductive circuits up to 15 amp. at 110 volts D.C. without damage to the contacts. The proving contacts, as on standard relays, are silver to carbon. All contacts are brought out independently to terminal points.

When a point machine is operating, the current taken by the motor starts with a surge and drops quickly while the motor gains speed and the bolt is withdrawn, it then rises again while moving the blades, and still further as the blades are being closed, and then falls off as the bolt is replaced. Should the points fail to complete their stroke due to an obstruction, the motor will continue to run with the clutch slipping, the current rising to 10 amperes or a figure predetermined by the clutch setting.

An overload device is used to discriminate between the starting and operating surges and the higher current drawn when the motor is running on the clutch. This device comprises a standard British Post Office 3,000 type relay operated in series with a thermistor. The thermistor has a negative temperature coefficient, thus, when cold, the resistance is high and when warmed drops sharply ; it also possesses a reliable time constant, such that, for a given applied voltage, the time taken to cause the reduction of resistance is almost constant. The thermistor bead is contained in a sealed evacuated tube which ensures that the operation of the bead is virtually unaffected by ambient temperature.

To return to the operation of the contactors : if the points fail to close and the motor runs with the clutch slipping, a current of 10 amperes is passing through a low resistor. Across this resistor is connected the low resistance winding of the P.O. relay in series with the thermistor. The motor current of 10 amperes now produces the required voltage drop to cause the thermistor circuit to operate the P.O. type overload relay after a delay of three seconds. Operation of this relay causes the contactor circuit to be opened and the overload relay to be held operated. It should be noted that the overload relay can be made to operate at any required current value from 6 to 20 amperes by adjustment of a tap on the resistor.

With the opening of either coil circuits, the operated contacts open, breaking the motor circuit and allowing the thermistor to reset.

A feature of the type CU contactor is that all heavy current connections are provided with two ' plug-in ' blades in parallel to ensure adequate current carrying capacity. Should economy of power be important, the unit may be used as a normally de-energised contactor and, since all operating connections are brought out to terminals, it may be controlled over the

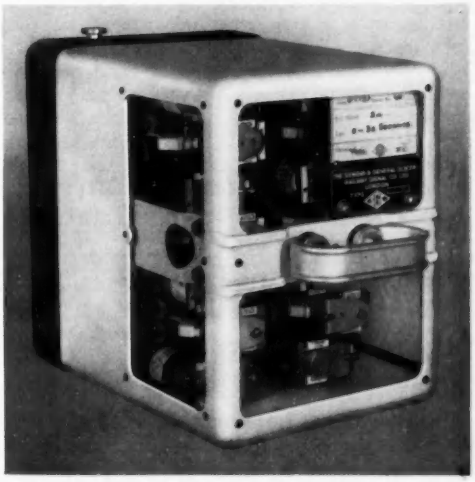

Fig. 47.—Type CT 130 time delay unit for use in railway signalling circuits.

cut off contacts of the machine. It is necessary to use one contactor per machine since it is impossible to discriminate between two machines when one is on normal load and the other is on overload.

Fig. 48.—Type PG earth leakage detector for use in railway signalling supply systems.

TIME DELAY UNIT.

The time delay unit consists of fourteen P.O. type 3,000 relays, actuated through a set of sequences by time controlling relays in such a way that, automatically, thirty different combinations of relay energisations can be set up sequentially. Two terminal strapping banks permit the selection of one out of the total possible relay combinations for actuating a final relay at a predetermined time from the first instant of applying current to the unit. The contacts of the relay can be used to close or open external circuits carrying up to 5 amp. at 250 volt A.C. or D.C., with suitable quenching. If the supply to the unit is interrupted before the timing is completed, all relays immediately reset to "normal" and the full selected time will elapse between the next application of current and operation of the final relay. The unit, which is illustrated in fig. 47 is normally made for operation on 12 or 24 volt D.C.

EARTH LEAKAGE DETECTORS.

The need for giving visual or other warning of leakages to earth from one or both sides of a railway signalling power supply system, arises from the fact that such leakage, in combination with certain circuit conditions, might be sufficient to prevent the release of line relays in vital signalling circuits, or, in severe cases, to operate such relays from the de-energised position Unlike earth leakage detection devices in main electricity distribution systems, where the primary requirement is to break the supply instantly upon the occurrence of a serious earth leakage, the requirements of railway signalling do not call for instantaneous action. Advantage is taken of this fact, in the equipment under review (fig. 48), to render it relatively immune from inductive surges and kicks, by integrating a resultant of the leakage over a period of some $\frac{1}{10}$ to $\frac{1}{2}$ second. To prevent any interference between one side, or the other, the positive and negative sides of the circuit are tested alternately. A pulsing relay having approximately equal periods of energisation and release, connects a capacitor to one line during energisation and, when de-energised, offers any accumulated charge to a detector relay. Once tripped, the detector changes a green indicator to red, and this remains until manually reset when the green indicator reappears. The other side of the supply is similarly tested with the pulsing relay de-energised and energised respectively.

A sensitivity control is provided for each side of the supply and, under favourable conditions, leakages as low as 1 mA can be detected. Models for 24 volt and 110 volt D.C. and for 110 volt A.C. are available, the last-named having a plug-in capacity balance unit as an accessory (fig. 49). The need for this arises from the

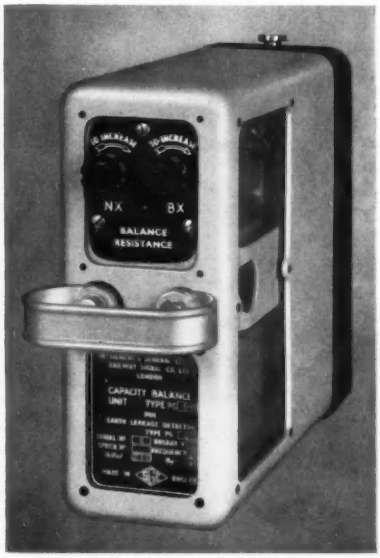

Fig. 49.—Type PG capacity balance unit for use with earth leakage detector.

fact that, with A.C. systems, there is an inherent leak to earth through the capacity of cables, transformer windings, motor windings, and so forth which, unless balanced out in the detector, may screen a dangerous fault leakage which is almost invariably resistive in character.

Fig. 50.—Type CL 450 D.C. interlocked point relay.

The units are similar in appearance to the plug-in relays manufactured by the S.G.E. and when mounted on a rack line up with them harmoniously.

INTERLOCKING RELAYS, TYPE CL.

In modern relay interlocking systems for railway signalling circuits, relays are sometimes used which latch up and disconnect their coils after each operation, giving the advantages of:

(1) Simpler circuit arrangements.
(2) Saving in power consumption.
(3) Power supply failures cause no disturbance to circuits set up.

In the past, mechanical latching has been used, but this needs more maintenance than is desirable in signalling relays which are sealed to prevent interference, and the use of latched relays has therefore been restricted.

A new range of latched relays, type CL, has just been introduced in which the contacts are held very firmly closed by permanent magnets, this construction having been made possible by modern developments in magnetic alloys.

The type CL relay illustrated in fig. 50 contains two units mechanically interlocked so that only one can be energised at a time.

There are two coils in each latched unit. One is used to pull up an armature, which operates the contacts and carries a small permanent magnet up against a pole face behind which is the other coil. The permanent magnet is attracted to this pole face and supports the contacts securely in the operated position until this other coil is energised to a polarity opposite to that of the magnet, when the armature is repelled and the contacts revert to the de-energised position. Precautions are taken in the design of the magnetic circuits to prevent weakening or reversal of the permanent magnet.

The principle of "magnetic latching", as it is called, has been introduced by the S.G.E. and completely obviates the complications entailed by mechanical systems of latching and enables the relays to operate for long periods without attention, in the same way as ordinary unlatched relays.

MARINE ELECTRICAL EQUIPMENT.

During the past year several vessels have gone into commission fitted throughout with G.E.C. electrical machinery. Perhaps the most interesting is the San Florentino, an 18,000-ton tanker which has been described in an earlier issue of this Journal* and her all-A.C. installation has aroused considerable interest. A sister ship, the San Fernando, is now in service and four similar equipments are in hand for vessels of the same type.

The tanker Hemidonax entered service in December, 1953, to be followed shortly by the Hemifuses, and in due course by seven similar vessels. These also carry A.C. installations based on a specification very carefully prepared by Shell Tankers, Ltd.

The second diesel-electric pilot vessel for the Mersey Docks and Harbour Board completed her trials in November. The machinery of this vessel, the Edmund Gardner, is in every way similar to the Sir Thomas Brocklebank which has proved so successful in service. The ship is propelled by a 920 s.h.p. motor which draws its power from two 375 kW, 363 volt diesel-driven D.C. generators. Coupled in tandem to the main propulsion generators are two 80 kW, 220 volt generators for supplying the auxiliary power.

The 10,500-ton passenger and cargo liner Patonga for the P. & O. Steam Navigation Co., Ltd., entered service in November, 1953, and is equipped with a complete plural starting system. During the present year four more vessels for this company will be commissioned, all provided

* "A Modern Tanker Using Alternating Current," by C. P. HARRISON, M.I.Mar.E., *G.E.C. Jour.*, Vol. XX, No. 3, July, 1953.

with plural starting gear. The 21,000-ton Santa Maria for the Cia. Colonial de Navegaçao is now in service with a comprehensive plural starting system similar to that installed in her sister ship the Vera Cruz ; as in the case of the Vera Cruz the ship's main switchboard includes line contact circuit breakers which are back-of-board mounted but operated from the front of the board.

The new liner Kungsholm for the Svenska Amerika Line is now in service and also employs circuit breakers in a dead front switchboard. This vessel, now on the North America run, has a luminous call system. Cold cathode tubes are used for the illumination of a number of the main public rooms.

Mention has already been made of the first passenger liner to be built in this country employing alternating current throughout.* Orders already received include four 1,040 kW, 440 volt, 60 cycle, 3-phase alternators, over 60 squirrel cage motors ranging from 2 to 335 h.p. a 54-panel main switchboard over 55 ft. in length, together with port and starboard group starter boards. A typical group starter board is seen in fig. 51. The main board will be one of the largest switchboards of the sheet steel cubicle type to be installed in a ship. The vessel is being fitted with stabilisers for which the Company is supplying electrical equipment, which includes a 50 h.p. slipring motor together with an automatic contactor type stator/rotor starting panel and a 10 h.p. squirrel cage motor with a DTL starter.

* "Progress and Development." *G.E.C. Journal*, Vol. XX. No. 1, p. 28, January, 1953.

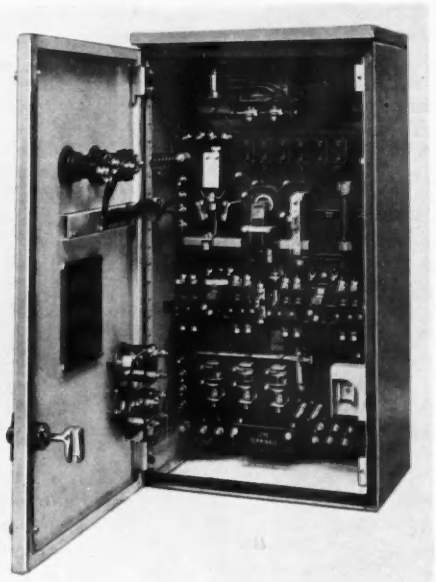

Fig. 52.—Direct-to-line starter for controlling motors for oil purifiers.

Some 50 D.C. motors ranging from 0·9 h.p. to 73 h.p. for a new Booth Line vessel being built by Cammell Laird & Co., Ltd., are also in hand.

For eight tankers now building in this country, a total of sixteen 50 h.p., 440 volt, 60 cycle,

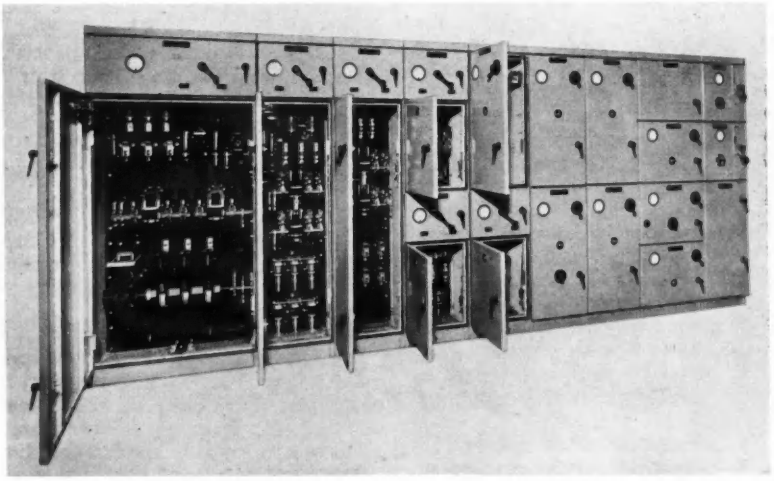

Fig. 51.—A typical group starter board of the cubicle type for service on board ship.

3-phase squirrel cage motors, with D.T.L. starters and alarm panels, have been supplied for the steering gear equipment, and similar orders have been received for fifteen tankers building on the Continent.

The Company is supplying the complete electrical equipment for two tankers building in this country for The Afran Transport Co., Ltd. The contract covers 500 kW, 440 volt turbo-alternators, 100 kW auxiliary alternators, squirrel cage motors ranging from $\frac{1}{3}$ to 137 h.p., the main switchboard, group starter boards and transformers. Similar orders have also been placed for another tanker and two ore carriers.

A range of totally enclosed direct-to-line starters (fig. 52) suitable for bulkhead mounting has been developed for motors up to $15\frac{1}{2}$ h.p., driving oil purifiers. The overcurrent relays are automatically short-circuited for a period of up to $2\frac{1}{2}$ minutes during starting so that there is no risk of the starters being tripped by the heavy initial current taken by the machine. These starters are arranged for local and remote control. Also developed during the year are single and two-speed direct-to-line starters for use with motors up to $12\frac{1}{2}$ h.p., and built for bulkhead mounting.

The 28,000-ton passenger liners Arcadia and Iberia for the P. & O. Steam Navigation Co. Ltd., will be shortly in service and will be illuminated throughout by fittings of G.E.C. design and manufacture. Both hot and cold cathode tubes are being used for the lighting of the public rooms, and a great number of specially designed lighting fittings for tungsten lamps are also being supplied. In both these ships telephone exchanges, fire alarms and luminous call systems are being installed.

Of particular interest is a diving bell which has recently been brought into service by the Admiralty at the Gosport Submarine Escape Training Establishment. The operator in the diving bell is enabled to follow closely the movement of the person escaping from a hatch in the base of a 100 ft. deep tank, the hoist motor which raises and lowers the diving bell being precisely controlled to permit exact positioning at accurately controlled speeds. The motor is supplied from a Ward-Leonard set, the fields of which are governed by a control exciter of the laminated field type via a watertight master speed and direction controller located inside the diving bell.

AERONAUTICAL EQUIPMENT.

The G.E.C. has made an intensive study of the design of aircraft galley equipment, with which the question of weight is naturally very important. In collaboration with British Overseas Airways, a single compartment aircraft oven has been designed incorporating a fan to distribute the hot air evenly over the food. This oven is now standardised for use on the "Comet" and "Britannia" airliners. Other equipment supplied to B.O.A.C. includes a special beverage container, and a $\frac{1}{2}$-gallon water heater for the toilets.

For the K.L.M. Royal Dutch Airlines a double-compartment air-circulation oven has been designed as standard equipment for Super-constellation aircraft. This oven is also used by Qantas Empire Airways, Trans-Canada Airlines and other operators of Super-Constellation aircraft. G.E.C. galley equipment is also used on the "Viking" aircraft of the Queen's Flight. The Company has supplied galley equipment for the "Viscount" and "Ambassador" aircraft, including a special lightweight food and liquid container of which many hundreds are in use. Most of this equipment operates on the standard 28 volt D.C. supply.

Due to the complexities of the modern high-speed bomber, the galley has been eliminated and individual crew members take meals cooked on the G.E.C. aircraft ration-heater while at station in the aircraft.

The Company has developed a material known as G.E.C. Heavy Alloy, which is the only practical material available for use where a large weight has to be accommodated in a small space. One of its most outstanding applications is for mass-balancing aircraft control services, ailerons, rudders and elevators; many British aircraft, both service and civil, now use it for this purpose. G.E.C. Heavy Alloy is a metallurgical product with a density up to 17·0 grams/c.c. A new series of alloys is now available with densities exceeding 18·0 grams/c.c., which approaches the theoretical density of tungsten. All these alloys are machinable and possess mechanical properties comparable with those of the existing alloy.

More recently a high-density alloy has been developed which is also available in the form of sheet of limited size. It is characterised by its much higher elongation with no corresponding decrease in tensile strength.

Electronic Machine Control

One of the most important developments in the field of electronic control of small motors has been a unit for use with the Witton-James-Wood Autopaster for rotary printing presses, to which reference is made in the description of reelstand

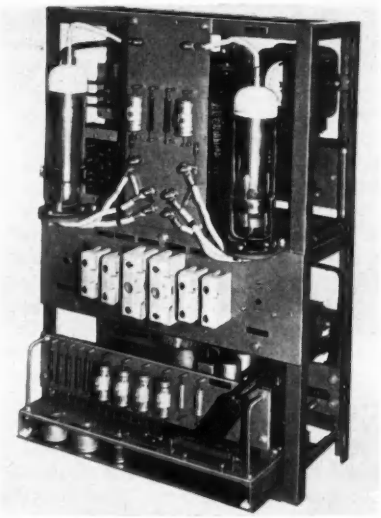

Fig. 53.—Electronic control equipment for service with a Witton-James-Wood Autopaster for rotary printing presses.

equipment in the section "Industrial and General Electrification." It enables a new reel of newsprint to be spliced to an expiring reel without slowing the printing press. Formerly, for matching the peripheral speed of the new reel of paper with that of the paper passing into the printing press a variable speed gear was used. With the new electronic device this speed match is effected by means of two tacho-generators, one driven by the press and the other by the new reel of paper. To allow for the varying diameters of different reels, a caliper device passes over the new reel and automatically adjusts a potentiometer connected across the armature of the reel tacho-generator. The difference between the voltage across this potentiometer and the output voltage from the press tacho-generator is fed to the electronic control equipment (fig. 53) which provides the power for the motor driving the new reel during the splicing operation. A current limit feature ensures that the reel is accelerated to the correct speed in the minimum time without risk of overloading any part of the equipment. In practice the speed match obtained has been found to be accurate and reliable resulting in an increase in the overall efficiency of the Autopaster. Sixty-three equipments have been supplied or are in course of construction.

An example of the precision control of medium-size machines by electronic means is an installation at Chance Bros., Ltd., for the accurate speed control of bore-hole pumps on test at the Works. Power for the pump motors is derived from a 190 kVA variable frequency alternator driven by a D.C. motor. The motor armature is supplied from a grid-controlled steel tank mercury arc rectifier, the output voltage of which is regulated by an electronic control amplifier. The equipment enables the frequency of the supply to be controlled to within $\pm \frac{1}{4}$ of a cycle over a range of 30 to 60 cycles. A somewhat similar type of precision speed control is also being made for the fan motor of a wind tunnel at the College of Aeronautics.

As regards machine-tool drives, the thyratron equipment for supplying the feed motors of a Kendal and Gent plano-miller (fig. 54) is deserving of mention. This machine tool was exhibited at the International Machine Tool Exhibition at Olympia in 1952. By means of electronic control equipments, the normal working ranges of feed speeds are covered, together with a rapid traverse, without the use of variable-ratio gear boxes, the operator setting the speed by means of a small rotary potentiometer.

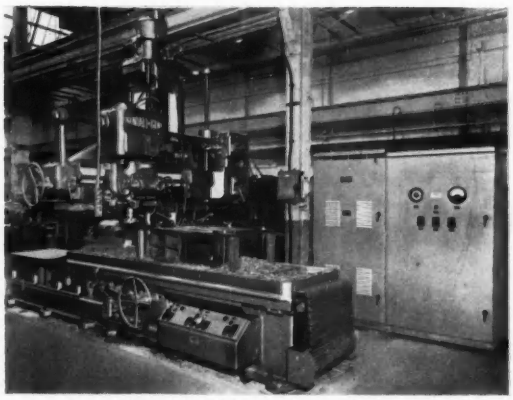

Fig. 54.—A Kendal and Gent plano-miller arranged for electronic control.

Plastics

During the past year, the thermo-plastic injection moulding plant at Witton Moulded Insulation Works has been greatly increased by the acquisition of several new machines, including one of 32 oz. capacity (fig. 55). The new plant has made possible the production in polystyrene of large refrigerator components and of radio and television fronts, up to 26 oz. in weight and over 2 sq. ft. in projected area. In order to meet the increasingly heavy demand for this type of article, more plant and buildings are being provided.

A new product moulded in polystyrene, and assembled into a complete article, is the Bijou torch. This is produced with bodies of red, green, black and cream, and further lines of torches will shortly be in production.

Another development in thermo-plastics is the production of a lavatory cistern of modern design with a high gloss finish. It is moulded in one of the oldest moulding materials, Wittonite, with the aid of semi-automatic press control gear developed within the Works.

The unique properties of nylon have been exploited in the form of a variety of mouldings where the conditions warrant the high cost of this material.

An interesting development of an existing standard line has been the adaptation of the Mutac switch to meet Canadian specifications which require that the switches be capable of performing 10,000 reversals with an instantaneous inrush current of over 90 amp. This switch, as now marketed in Canada, is rated at 15 amp. 120 volt (fig. 56).

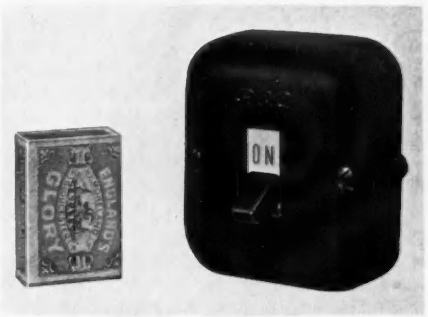

Fig. 56.—15 amp. Mutac moulded switch body in comparison with the size of a matchbox.

For some years past, the principle of slow-break alternating current switching has been applied to 30 amp., 230 volt double-pole switches and switch fuses. It has now been extended to 60 amp., 500 volt double pole models, and production has also started on 60 amp., 500 volt, 3-phase switches capable of handling inductive loads.

The speed of break of these switches in normal operation has been shown by oscillograms to correspond very closely to that required to ensure minimum loss of energy and thus least damage to contacts. It has been proved experimentally that both the gap between the contacts and the speed of operation can vary between quite wide limits without materially affecting the performance and life of the switch.

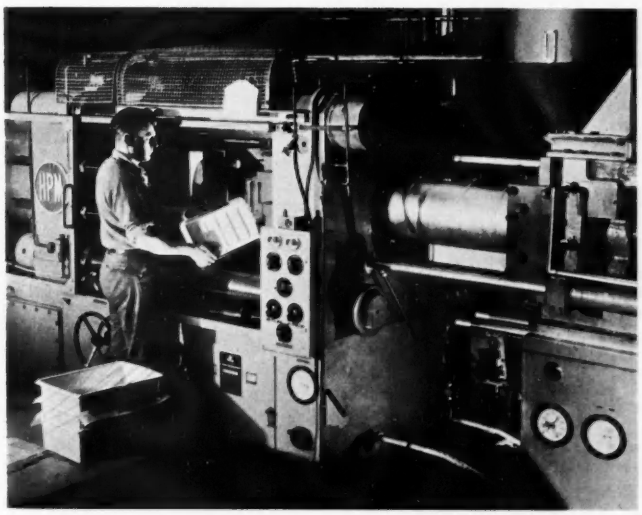

Fig. 55.—A refrigerator tray being taken from a large injection moulding press.

Industrial and Domestic Heating Equipment

A recent addition to the range of special purpose high frequency heating equipment is a machine (fig. 57) for surface hardening steel bars of $\frac{1}{2}$ in. to $1\frac{1}{4}$ in. diameter in a continuous operation. The bars are placed one at a time at the top of an inclined V-slide, down which they pass through the heating coil and then through the quench box, afterwards sliding down a chute into a collection basket. Two driven V-rollers, one above and one below the heating coil and geared together, accurately control the speed at which the bars are allowed to move (fig. 58). By altering the speed, the thickness of the hardened case may be varied and skin thicknesses of 0·02 in. to 0·1 in. are obtainable in this way. Power, provided by a 25 kW high frequency generator, is concentrated into a short axial length of bar surface, causing rapid heating to hardening temperature. The machine will harden 1 in. bars to a depth of 0·04 in. at a speed of 30 in. a minute.

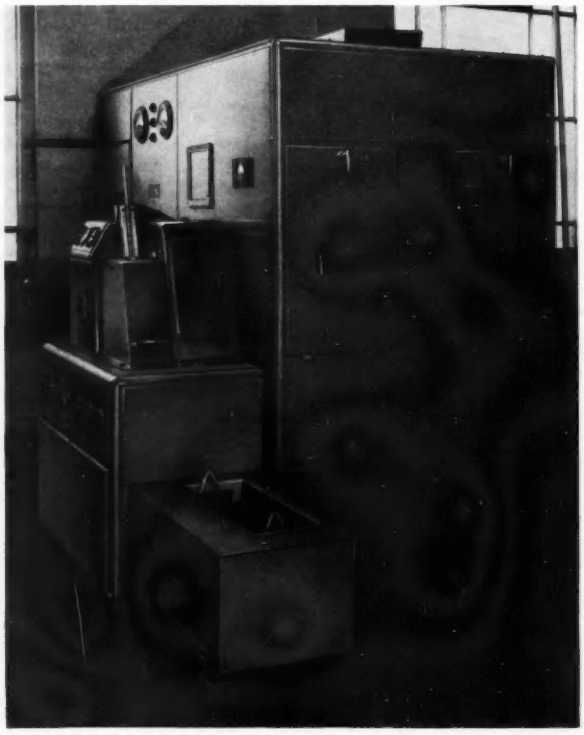

Fig. 57.—H.F. induction heating equipment for surface hardening steel bars.

A new item in the field of radiant heating is an internal reflector lamp type of oven (fig. 59) for softening "Perspex" before shaping. The Canberra aircraft nosepiece in the foreground of the illustration has been moulded from a "Perspex" sheet softened in this oven. Similar ovens are used for softening other thermoplastic materials, e.g. polythene and rigid P.V.C. Control units are available which enable the plastic to be heated rapidly to moulding temperature, using the full available intensity, and then to be held at this temperature at a reduced intensity until required for use.

The growing use of radiant heating for the drying of finishes on wood is exemplified by the oven for force-drying cellulose finishing lacquers on veneered radio and television cabinets shown in fig. 60. It is 32 ft. long, has a maximum loading of 46 kW and an operating loading of 35 kW. In a 40-hour week this oven will force-dry three coats of lacquer—the drying time is $6\frac{1}{4}$ minutes per coat—on 2,500 to 3,000 small cabinets, placed two per carrier. Alternatively, half as many larger cabinets may be treated. The saving in drying time effected by radiant heating can greatly simplify the handling of work in wood finishing departments; in addition, compact conveyors can be installed to take articles through the various spraying, drying and flatting sections, thereby saving effort and floor space and minimising the risk of damage.

Electric heating is being increasingly used for destroying unwanted materials. An incinerator providing an efficient, clean and economical means of disposing of sanitary wear and used surgical dressings has been produced (fig. 61). The body of the incinerator is a light alloy casting, with a charging door operated by a pedal, and the main heater element is a solid nickel-chrome rod, rated at 750 watts on a voltage of 4·6. By means of a special clutch arrangement the element is energised only every fourth time

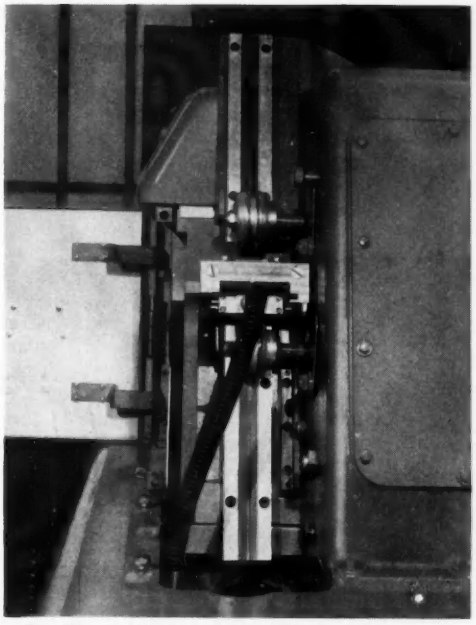

Fig. 58.—Detail view of the V-slide and rollers on the bar hardening machine.

the charging door is opened, an economy measure which also gives a prolonged element life.

To keep the flues warm, for smoke suppression, two auxiliary heaters of about 100 watts are fitted. These are kept on all the time the incinerator is connected to the mains except when the main element is on. Besides warming the flues the auxiliary heaters dry the charges, so leading to more efficient destruction. There is a choice of two flue adaptors, enabling the flue to be taken vertically up or back through a wall, and the unit can be used on the normal single phase supply between 100/125 and 200/250 volts.

Several unusual features are incorporated in another recently developed unit, shown in fig. 62. This is for destroying old and dirty banknotes that have been withdrawn from circulation. Two major considerations had to be borne in mind: the high temperature generated by the burning paper, and the need for security precautions. The destructor chamber measures 18 in. square by 24 in. high, and the high temperature generated inside makes it necessary to use 4½ in. of thermal insulation to keep the outside surface temperature at a reasonable level. For security there are double charging doors, one inside the other, with a padlock on the outer one. A padlock is also fitted to the ash drawer. A glass-covered spy-hole projects from the front of

Fig. 59.—The aircraft nosepiece shown here was moulded from a "Perspex" sheet softened in the oven in the background.

the destructor to facilitate inspection during burning.

The unit has a rocking hearth, motor driven through a crank arm, the movement ensuring separation of the notes and effectively breaking up the ash. Elements are controlled by a time switch and a hand-operated isolator switch. The destructor has a capacity of about 65,000 treasury notes per charge, and will destroy some 200,000 notes per day ; the rating is 6 kW.

In space heating, attention has been concentrated on the further development of the storage system. The thermal storage space heater shown in fig. 63 is designed to use electrical energy during the night, at an " off-peak " period, and to give out this energy as heat during the following day. It is particularly useful for heating in shops, offices, stores or any industrial or commercial premises where it is desirable to avoid any increase in maximum demand, or where favourable tariffs for night loads are available. Electrical loading is $1\frac{1}{2}$ kW and, with a charging period of eight hours, 56 per cent. of the heat output is dissipated during the period in which the building is normally occupied.

The storage medium consists of twenty concrete blocks of a special mix, which are housed in a sheet metal case measuring overall 1 ft. by 2 ft. $2\frac{1}{2}$ in. by 2 ft. $5\frac{1}{2}$ in. high. The elements are arranged to fit in the centre of the storage mass,

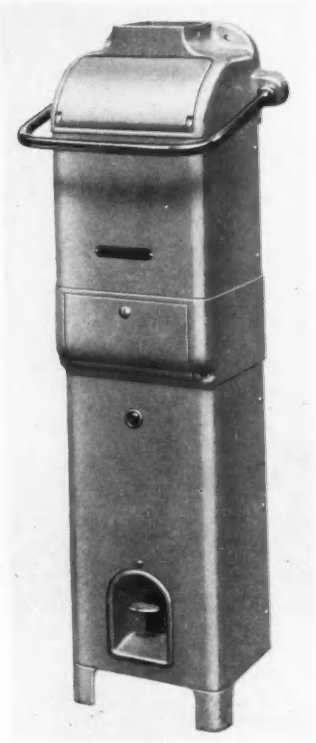

Fig. 61 (*right*).—Incinerator for the disposal of sanitary wear and used surgical dressings.

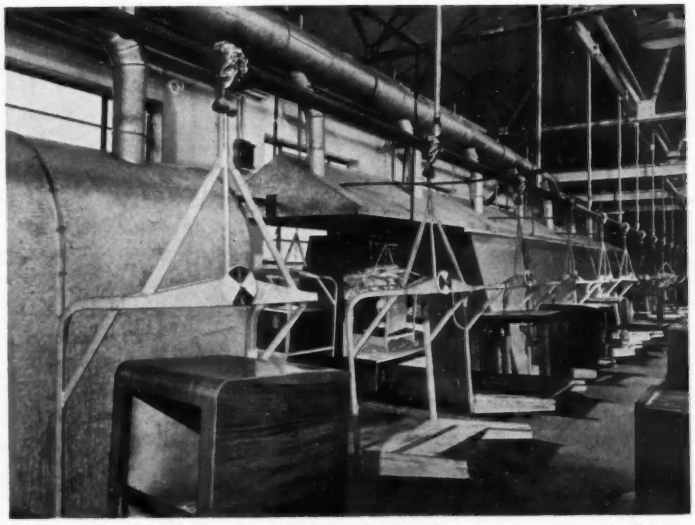

Fig. 60.—Oven for force-drying cellulose finishing lacquers on veneered cabinets.

Fig. 62.—The banknote destructor, with the charging doors open, showing the old notes being loaded inside. In the detail view, on the right, may be seen the controls and luminous signals. The projecting spy-hole is in the centre just below the charging doors.

and the total weight of the unit is about 400 lb. The heater can be assembled easily on site and is finished in an attractive polychromatic bronze.

The range of immersion heaters has been increased by the addition of a 9 kW heater for use in industrial tanks and cylinders. Easy to install, it consists of three cartridge-type elements housed in heavily tinned pocket tubes, brazed to the brass head. The elements may be withdrawn without draining the containers.

Much attention has been given to the development of household appliances of sound design and attractive appearance. Fig. 64 shows a new thermostatically controlled lightweight iron. It is available either with a cream vitreous enamel finish, weight $3\frac{1}{4}$ lb., or with a chromium-plated finish, weight $2\frac{1}{3}$ lb. The very desirable reduction in weight has been achieved by using an aluminium alloy sole plate, but care has been taken to ensure that the iron remains sufficiently

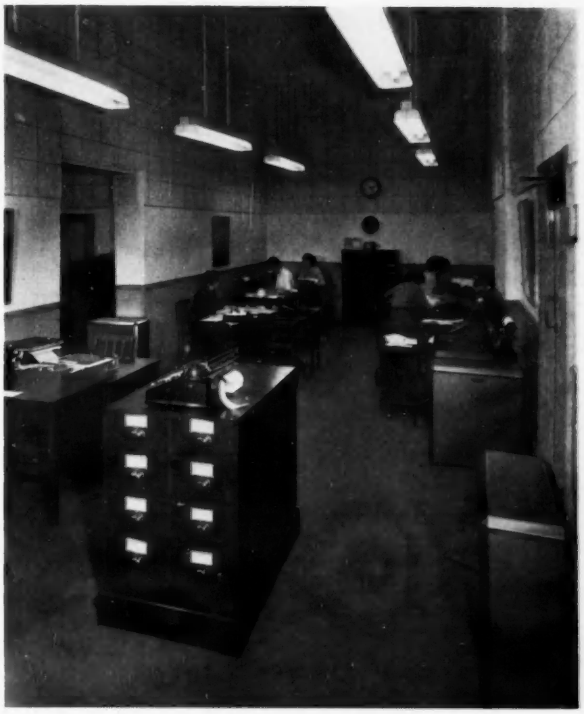

Fig. 63.—Thermal storage space heaters in the Midland Bank, Kingsway, London.

Fig. 64.—Thermostatically controlled light-weight iron.

heavy for the satisfactory removal of creases. It has a 750 watt sheathed wire heating element and a snap action thermostat switch which eliminates radio and television interference.

There have been several developments in the field of agricultural heating. Notable among these is a range of units incorporating Woods fans and G.E.C. duct air heaters for platform grain driers and ventilated silos (fig. 65). A new concrete sack platform using Transverco beams and special units has been designed which can be easily assembled by farm labour. The space beneath the platform is unobstructed, affording efficient air distribution.

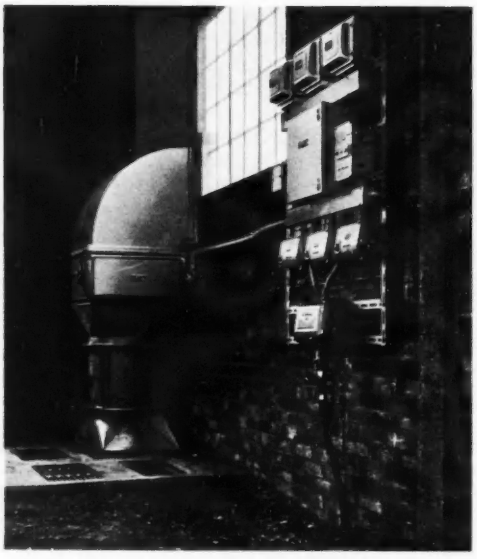

Fig. 65.—Platform grain drying installation with vertically mounted Aerofoil fan at Rothamstead Experimental Farm.

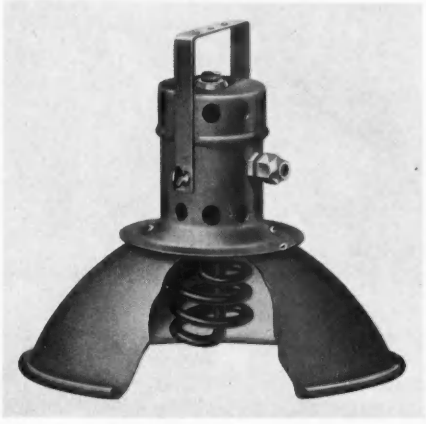

Fig. 66.—Dull-emitter infra-red heater showing sheathed wire element.

The range of infra-red heaters for pigs and poultry has been extended by the introduction of a single lamp unit and one of the dull-emitter type with an unbreakable sheathed wire element (fig. 66). The lampholders and connections are completely enclosed as a protective measure.

Mains voltage soil warming cables, particularly suitable for use by amateur gardeners, have been introduced. They are insulated with polythene, and incorporate a tinned copper wire braided earth screen for electrical and mechanical protection.

Instruments

The constant demand for ever higher precision in electrical measurement and control has led to the marketing of a range of precision potentiometer units. These range in size from a little over an inch in diameter to about four inches, and incorporate linear toroidally wound resistance elements. The resistance range covered is from a few hundred ohms to about 500,000.

Fig. 67.—Resistance meter.

High discrimination of small movements is obtained by putting the maximum number of wire turns into the space available, with due regard to insulation problems, and using wiping contacts giving a narrow arc of contact. A variation from perfect linearity of as little as 0·1 per cent is obtainable over most of the range covered. A specially developed process for making a sound electrical and rigid mechanical contact to one or a group of wires on a winding enables a precise start and finish connection to be made. Accurate intermediate tappings are furnished to meet users' requirements. Ganged assemblies, accurately aligned, can be produced up to any reasonable number, and operating torque figures are kept to the minimum.

Further developments in this field are aimed at the production of sub-miniature micro-torque capsules suitable for direct incorporation into instruments, and the production of high accuracy special law elements which may be incorporated in the present range of housing sizes.

Several new types of transducer have been developed for use with the system for remote indication and recording of mechanical quantities, pressures, weights, temperatures, etc. described in an earlier Progress Article.* The transducers have improved performance and are smaller than those used hitherto. This system comprises only a transducer and an instrument, no auxiliary equipment being required.

A valve amplifier has been built for the measurement of small alternating leakage currents to within an accuracy of at least 1 per cent. The range of the instrument is from 1 μA to 500 mA, but it can be easily modified so as to measure currents greater than this. Two slightly differing models have been made. The first, for laboratory use, has a multi-range voltmeter built into the front panel ; the second, for Works use, dispenses with the lowest current range but has a " test " range instead. This is designed for the testing of heating elements, and shows at a glance whether the leakage current is above or below a specified limit. The instrument operates on mains voltage, and the H.T. is stabilised by a KT66 stabilising circuit after being smoothed. The currents to be measured are fed through a multi-range switch and a bank of resistances to a two-stage, resistance-capacity coupled amplifier.

An instrument for measuring electrical resistance within the range $0{\cdot}3 \times 10^6$ to $3{,}000 \times 10^6$ ohms has been developed and is shown in fig. 67. It is suitable for field measurements, being of compact design and housed in a robust case ; power is obtained from dry batteries or a mains unit. The instrument comprises two resistor-capacitor circuits : a timing circuit and a measuring circuit, both fed from the same supply source. The resistance to be measured is connected in series with the capacitor in the measuring circuit, and the time taken for this capacitor to reach a pre-determined voltage is recorded on an electro-magnetic counter in the timing circuit. The counter registers the number

G.E.C. Journal, Vol. XIX, No. 1, pp. 67, 68, January, 1952.

of charge-discharge cycles of the capacitor in the timing circuit, these being proportional to units of resistance which may be 0·1, 1·0 or 10 megohms, according to the range selected. Accuracy closer than ± 5 per cent can be expected on measurements which record 20 or more units ; below this, accuracy will be within one unit.

New temperature testing equipment, giving improved measuring precision and embodying experience gained on earlier apparatus during the past 15-20 years, has been developed for tests on lighting fittings. During its design, the conditions have been established for thermo-couples to give accurate measurement of surface temperatures on poor thermal conductors such as glass and plastics.

A new Schlieren apparatus has been built for use in the Laboratory for the study of hot air flow around lighting equipment. It is arranged so that air-flows can be studied while the equipment is on test in the draught-free enclosure in which temperatures are measured. The optical system is a rearrangement of that developed at the Research Laboratories in 1933 and has, among other advantages, twice the sensitivity of conventional systems. The present arrangement permits the use of four diaphragms giving different presentations, mounted on a turret head so that they can be brought into use without adjustment. One is the conventional knife-edge ; another shows the air streams as white on a green ground, the apparatus on test being in silhouette, and is equally sensitive to displacements in any direction ; in another the air streams appear in colours of the spectrum on a coloured ground. The apparatus is adapted to the photography of the effects as well as to their display.

Medical Equipment.

The G.E.C. has provided the special heating elements for a new incubator, built by Oxygenaire (London) Ltd., which is designed to save the lives of premature babies of whom more than 4,000 die annually in Great Britain.

The incubator, which is approved by leading paediatricians, occupies little more space than a cot and provides accurately controlled heat and an air/oxygen atmosphere of carefully controlled humidity. X-ray photographs can be taken, blood transfusions given and operations performed without removing the infant from the incubator.

There are two models of the equipment. One is a portable unit (fig. 68), which can be plugged into the ambulance batteries, and which is used for transporting the baby from home to hospital. The more elaborate type for hospital use is completely self-contained. A controllable air intake is provided and filtered air can be mixed with the oxygen supply, as desired. In this way the infant can be transferred gradually from oxygen to air without any effect on temperature. In this incubator the baby remains until it is able to live in a normal atmosphere.

The chief developments in the Watson Radiological Equipment have been in improved accessory devices for special techniques. An example is an automatic serial changer for taking a number of radiographs in rapid succession of the gastro-intestinal tract while the patient swallows a ray-opaque substance. Facilities for intermediate screening are provided. The serial changer is fitted to the new T.250 tilting table, which has other interesting features. These include a motor-driven tube diaphragm for reducing the dimensions of the X-ray beam to the area under examination, electro-magnetic brakes on all movements, and a continuous motion Potter-Bucky diaphragm.

The Watson radiographic camera unit designed for use with any standard X-ray generator, tube and tube-stand, enables a considerable economy in the use of X-ray film to be made. The unit consists of a light-tight tunnel with a fluorescent screen at one end and a special camera with 4 in. × 5 in. film slides at the other. The exposure is controlled automatically by a photo-electric device which integrates the light emitted by the fluorescent screen and ensures uniform film blackening.

Fig. 68.—Transportable type of incubator for the care of premature babies.

Telecommunications

TELEPHONES.

The SE50 two-motion selector (fig. 69), for use in Strowger type automatic telephone exchanges, incorporates many improvements on previous designs. Life-tests have shown that it is capable of handling over 5,000,000 calls without needing replacements or resetting. However, in case resetting should become necessary, possibly through misuse or rough handling, a datum on which all adjustments are based is included in the mechanism to guarantee accurate return to the factory settings.

The Australian Post Office has standardised the SE50 switch for local production throughout Australia, and it is also incorporated in the 6-link 50-line extensible private automatic exchange in place of the 2,000 type used hitherto. The new selector considerably increases the life of this exchange.

The SE50 is also used in a new series of private automatic exchanges (fig. 70) which provide up to eight simultaneous conversations per 50-line unit and can be connected to furnish P.A.X's of up to 400 lines or more. Permanent ground "throw-off" is incorporated. This releases a link after a suitable interval, when the link has been held by a line fault or by an extension user having left the receiver off. Provision is also made for the easy addition of code call facilities, tie-line equipment and conference facilities, the two latter within the board itself.

RADIO COMMUNICATIONS.

Two new pieces of V.H.F. multi-circuit radio telephone apparatus have been developed for working in the range 150-186 Mc/s. One

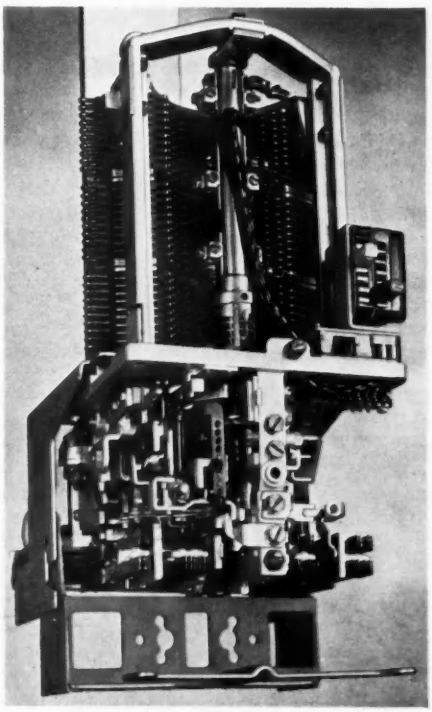

Fig. 69.—SE50 selector.

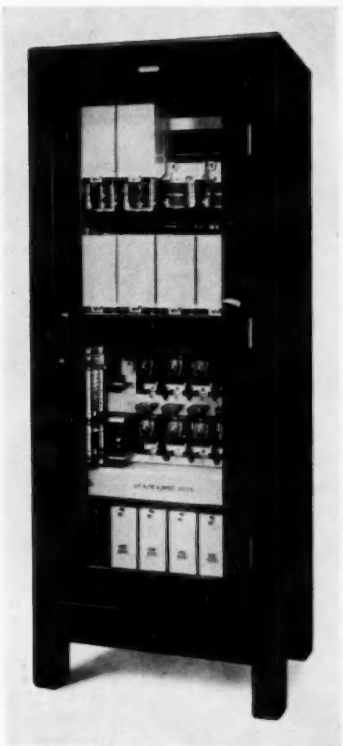

Fig. 70.—8-link, 50-line P.A.X. employing SE50 selectors.

is a 24-circuit trunk radio system for use on long-distance routes; it is contained in five 9 ft. high by 1 ft. 8½ in. by 8½ in. deep racksides (fig. 71), which house both the radio terminal and channel multiplexing equipment. The other, a 5-circuit junction radio system for use on short and medium haul routes, may also be used for spur routes associated with a main network. It is contained in one rackside 6 ft. high by 1 ft. 8½ in. wide by 8½ in. deep (fig. 72), again with both the radio and channelling equipment. Both these new systems employ frequency modulation and frequency division multiplexing, and repeater station equipment is available.

Frequency modulated U.H.F. trunk radio apparatus, operating in the 1,700-2,300 Mc/s band, and suitable for carrying large numbers of telephone and telegraph circuits or television signals, is now in production.

A development of particular interest in the radio communications field is a V.H.F. panoramic receiver (fig. 73), valuable for monitoring purposes and for a variety of laboratory uses. All received radio signals within a band of up to 10 Mc/s wide, at any frequency between 80 and 220 Mc/s, are displayed on a cathode ray tube in such a way that analysis may be made of frequency spacing, relative strength, type of modulation and so forth.

Fig. 71.—24-circuit V.H.F. trunk radio terminal equipment.

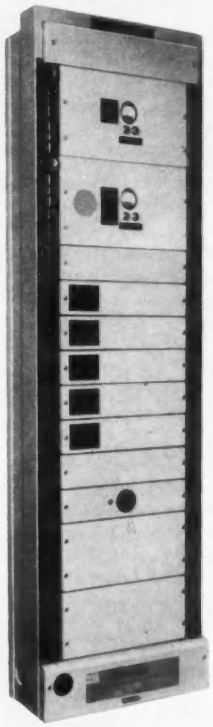

Fig. 72.—5-circuit V.H.F. junction radio terminal equipment.

Mobile V.H.F. radio-telephone equipment (fig. 74) capable of withstanding severe mechanical shocks and vibration has been designed for installation in Land Rovers and similar hard-sprung vehicles, now becoming increasingly popular with police and other authorities overseas. A special mounting assembly, virtually self-contained and easily transferable from one vehicle to another, was developed in collaboration with the Rover Co. Ltd.

Other radio-telephone apparatus (fig. 75), again intended for use under arduous conditions, has been designed, primarily for installation on the mobile drilling rigs now commonly used in new exploitation areas in the larger modern oilfields. While these rigs are operating the whole structure is subject to severe vibration, noise levels are very high and all equipment undergoes very rough handling. Moreover, the voltage of the power supply is liable to fluctuate considerably due to the wide variations in load.

The M.F./H.F. transmitter shown in fig. 76

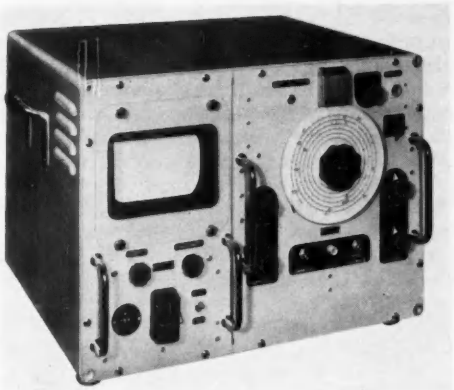

Fig. 73.—V.H.F. panoramic receiver.

makes a versatile addition to any general communications scheme. The most useful portions of the M.F. and H.F. radio spectrum are covered by one compact transmitter, thus making the equipment suitable for the smaller type of station working with aircraft or shipping, or as a standby for two or more higher powered transmitters. It may also be used as a radio beacon, for which an automatic keying unit can be provided. The modulator and power supplies are common but there are two R.F. units, one covering the M.F. range 300-600 kc/s, the other the H.F. range 2-16 Mc/s. A rotary key gives instant selection of the desired R.F. unit and of telephony or telegraphy facilities. Only one channel per R.F. unit is available at any one time, but as each unit can accommodate up to three crystals a total of six channels is available at very short notice. Retuning takes only a few seconds, and all important control knobs are fitted with graduated dials. Nominal R.F. output on telephony or telegraphy is 150 watts, and total consumption from 50/60 c/s A.C. mains of 100-110 or 200-250 volts is less than 1 kW at 100 per cent modulation. A number of these transmitters, specially modified for operation down to 200 kc/s. and 1·6 Mc/s on the appropriate ranges, has recently been supplied for ground-to-air communications.

A crystal-controlled, low power, medium wave broadcasting transmitter recently introduced meets the need for a reliable but relatively inexpensive unit for serving isolated regions. It is suitable for operation in temperate or tropical climates and, with the proper aerial system, will provide signals of good programme value over a useful area in and around a large town. This transmitter has a power output of approximately 150 watts within the frequency range 525-1,605 kc/s, and remote or time-controlled switching can easily be arranged. General performance conforms to that laid down in the American F.C.C. "Standards of Good Engineering Practice" for equipment of this type. The power requirement from single-phase A.C. mains of 50/60 c/s, 100-110 or 200-250 volts, is less than 1 kW at 100 per cent modulation.

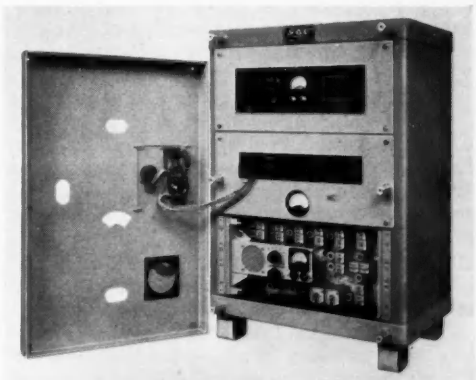

Fig. 75.—Radio telephone equipment designed for use on mobile drilling rigs in oilfields.

Fig. 74.—V.H.F. radio-telephone equipment on special mounting for installation in hard-sprung vehicles.

A modified version of the V.H.F. transmitting and receiving equipment that was used by the B.B.C. for relaying to the shore the television sound commentaries of the 1953 Oxford and Cambridge boat race and the Spithead naval review is now in production. A few technical details of the new version follow :

Overall Audio Response : 30 c/s to 30 kc/s within 3 db. Overall Distortion : less than 0·5 per cent at 30 per cent modulation from 50 c/s to 7,500 c/s ; less than 2 per cent at 100 per cent modulation from 50 c/s to 7,500 c/s. Transmitter Output : 15 watts up to 184 Mc/s. Receiver Sensitivity : 2 μV input for 26 db signal/noise ratio for an audio band width of 3 kc/s ; 2 μV input for 14 db signal/noise ratio for an audio band width of 12 kc/s. Hum and Noise Level (unweighted) : better than 54 db below 100 per cent modulation.

The aircraft radio control equipment shown in fig. 77 was designed and engineered at Radio Works to a Ministry of Supply performance specification. To meet its tests it was required to work continuously at temperatures ranging from — 57 deg. C. to + 54 deg. C. in a virtual vacuum ; it also had to work while subjected to sustained accelerations of 20 g and while being shaken at up to 150 times a second with an acceleration of 27 g.

The apparatus is being used to control the "Jindivic" pilotless target aircraft at the Australian Long Range Weapons Establishment at Woomera, and can be used for other purposes without major change. It consists of several small units which may be stowed in odd spaces in the aircraft and require no setting up after installation. As the equipment will be handled by unskilled persons it had to be made easy to install and, for the same reason, it was designed so that after leaving the factory only two controls are ever likely to need adjustment. Units are interchangeable within each type, valves may be changed, and operation over a wide range of supply volts is possible, all without readjustment. Restrictions on size and weight aggravated the problems of heat dissipation and led to the use of novel dissipation methods.

SUPERVISORY CONTROL EQUIPMENT.

An indicator board from which sub-station apparatus is controlled was recently completed for the Athens-Piraeus Electricity Company. Indication and control facilities for over 300 circuit breakers are provided, and 234 busbar voltages, feeder loads and so forth can be metered. D.C. signalling over pilot wires is used, and there is provision for telephone communication between the control station and the sub-stations.

CATHODE RAY TUBES.

The 14 in. rectangular television tubes with a 70° scanning angle are now in factory production. The bulbs incorporate a neutral filter glass screen which improves picture contrast in two ways: by minimising the effect of high ambient lighting and by reducing multiple reflections of picture elements.

Investigations into the use of increased scanning angles have led to the development of a 12 in. diameter flat-faced television tube with a 90° angle. This effects a reduction of about 5 in. in overall length, with a consequent saving in the size and cost of receiver cabinets. A portable television receiver incorporating one of these tubes was exhibited at the 1953 National Radio Show. Larger tubes of the same type are being designed.

Life-test facilities have been extended to enable rigid quality control to be maintained on the ever-increasing output from the factory. The facilities are applicable to any size of tube likely to be produced in the next few years. The pre-production unit has continued to manufacture numerous special oscillograph tubes, and has begun the production of storage tubes for use in digital computers. A high-quality 5-in. diameter view-finder tube, electrostatically focused and magnetically deflected, has been developed for use with television cameras.

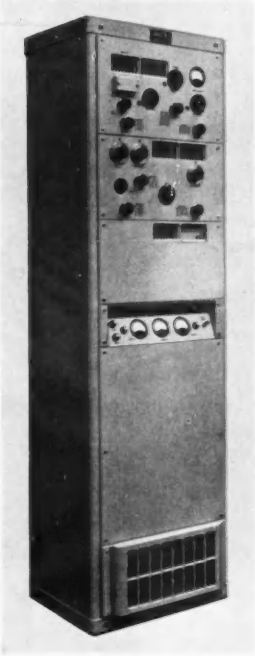

Fig. 76.—The versatile BRT 454 M.F. H.F. transmitter.

TELEVISION RECEIVERS.

The current programme consists primarily of a range of receivers using the 14 in. rectangular cathode ray tube, which gives the largest possible picture size compatible with compactness. Circuitry generally follows that of last year,

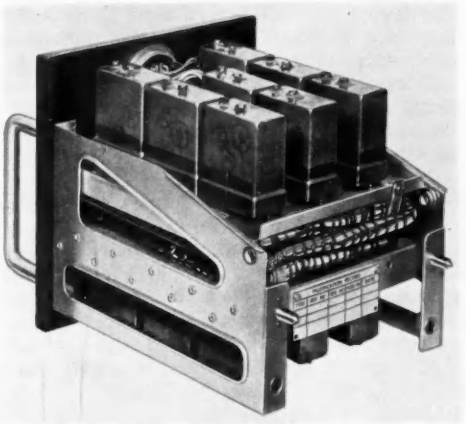

Fig. 77.—Relay unit for radio control of aircraft.

when the superhet technique was adopted in order to make the receivers tunable over the five main television channels, but many detail improvements have been incorporated. There has also been a change in the time base circuits to ensure greater stability and better linearity. Throughout receiver design the principal aim has been reliability. The biggest single contribution towards this has been the incorporation of a specially developed G.E.C. barretter to compensate for mains variations which, heretofore, have often led to receiver breakdowns.

A vertical chassis is employed and this, coupled with the fact that the cabinet can be lifted clear after the removal of only two screws, makes the components easily accessible. Another useful service feature is that the vision and sound receiver circuits are mounted on a quickly detachable sub-chassis.

Three receiver versions are available: a compact table model and two consoles, one of which has full length doors. There is also a console model using a 16 in. tube but with basically the same chassis as the 14 in. receivers.

Special fringe models are available for use in areas where, due to distance from the transmitter or for geographical reasons, the standard receivers will not ensure satisfactory reception. These have additional valve stages for added sensitivity, and special time base circuits to ensure maximum picture stability.

RADIO BROADCAST RECEIVERS.

A new table model A.C. receiver, which has a bakelite cabinet with a photographic finish simulating wood veneer, introduces the bandspread tuning technique into the G.E.C. range for the home market. Another new table receiver, in normal walnut bakelite and providing five-valve three-waveband reception, can be supplied for A.C. or A.C./D.C. operation.

The loudspeaker fret of the new radiogram shown in fig. 78 is made of a washable plastic material which may easily be wiped clean. The receiver is a new five-valve three-waveband design, and the record player will operate at $33\frac{1}{3}$, 45 and 78 r.p.m., with record-changing facilities at each speed. A cheaper alternative is provided by a radiogram having similar record-playing arrangements but a two-waveband receiver in a smaller cabinet.

Export models recently introduced include a five-valve A.C. receiver with a new presentation of the bandspread detent tuning technique, and radiogram versions of the high-class nine-valve bandspread receivers for A.C. or A.C./D.C. operation.

Fig. 78.—Radiogram with fret in washable plastic.

SOUND EQUIPMENT.

A smaller version of the high-quality ribbon microphone has been added to the range of sound equipment (fig. 79), its size making it more suitable for stage use. A die-formed duralumin ribbon gives it greater mechanical robustness.

Special features of a new high quality driver panel are the use of two Osram KT 66 valves in a new linear circuit, and heavy feed-back over a number of stages. This driver is particularly suitable for use with the 100/175 watt output panel described in last year's Progress Article*, and can operate up to twenty-four 100 watt panels or twelve 175 watt panels.

A 30 watt amplifier recently introduced is the first of the range to use the new Osram 2729 low-noise tetrode in the pre-amplifier stage.

Sound reproduction of outstanding quality is made possible by the use of the metal cone loudspeaker. In addition to its suitability for programme reproduction it is invaluable for studio monitoring purposes, and the unique properties of the cone result in frequency, transient and cross modulation distortion being very low, enabling faults in the transmission to be easily detected.

CRYSTAL VALVES.

The performance of point contact germanium diodes in the sound and vision detector circuits of television receivers has been studied, and the cause of the distortion which sometimes occurred has been established. As a result the GEX.34 now gives good performance in sound detector circuits and in vision detector circuits working at high signal levels. Where the video signal amplitude is less than about 3 volts the GEX. 35, with its high rectification efficiency, is recommended. The suitability of point contact diodes for use in other television receiver circuits is being investigated, since their small size, low capacitance and absence of heaters makes them more versatile than thermionic diodes.

A point contact germanium triode now in production is designed for operation in a variety of applications at audio and low radio frequencies. Life-tests indicate an expected life of many thousands of hours, provided that the collector dissipation is kept within the maximum rating of 100 mW. Plans are well advanced for small-scale production of another triode, intended for high-speed switching. It will have a cut-off frequency of not less than 10 Mc/s, and will be able to withstand higher ambient temperatures than the 35 deg. C. specified for the triode mentioned just previously.

Current gain of greater than unity in point contact triodes makes possible some novel oscillator circuits in which no external feed-back is required.

A superheterodyne radio receiver has been built in which crystal triode valves are used throughout. The output stage is a class B push-pull amplifier designed to take maximum advantage of the characteristics of the triodes. An audio output of 400 mW at 10 per cent distortion can be obtained, which is considerably higher than that normally associated with crystal triode amplifiers.

Fig. 79.—Junior ribbon microphone.

Simple power supply units having very good regulation can be built using junction diodes as mains rectifiers. The forward resistance of these diodes is many times lower than that obtainable with thermionic or selenium rectifiers.

SPECIAL GLASSES.

Two new glasses which form satisfactory seals with Kovar alloy have been developed, and one has been used on a manufacturing scale. There is no serious fall in their electrical resistivity even in excessively humid conditions and they can therefore be used in the tropics.

* *G.E.C. Journal*, Vol. XX, No. 1, p. 39, January, 1953.

Lamps and Lighting

FLUORESCENT TUBES.

Attention is now being given to the question of rationalising the wide variety of near-white colours which have come into being in various countries, and international agreement on a limited range may follow. The Osram organisation has been prominent in the discussions, and the Research Laboratories have submitted many experimental colours for consideration.

Further study has been devoted to the provision of an improved social colour from fluorescent tubes which will blend well with incandescent lighting. The Research Laboratories have produced a range of colours for this purpose using the double coating technique described in last year's Progress Article,* but now others with single coatings have been evolved which show considerable promise.

Improvements have also been made in the colour-rendering properties of " Natural " fluorescent tubes. The red and blue luminous outputs have each been increased by approximately 20 per cent without detriment either to colour appearance or declared luminous performance.

A fluorescent tube has been developed to radiate the near ultra-violet. It is more efficient than the familiar high-pressure mercury vapour black glass lamp and may be used effectively where irradiation over a large area is required, such as on fluorescent posters or for floodlighting a ballroom or theatre stage to obtain fluorescent effects. As they are made with clear glass these tubes generally have to be used with a black glass filter in the fitting, but this is cheaper than making the tubes themselves of black glass.

The declared average light output of Osram fluorescent tubes over the first 5,000 hours of life has been increased by 12½ per cent, and the declared life of the 18 in., 2 ft. and 3 ft. tubes has been increased to 5,000 hours, bringing them into line with the 4 ft., 5 ft. and 8 ft. sizes. These advances have been made as a result of close attention to details at all stages of manufacture. One factor affecting both life and luminous performance is the precise vacuum conditions during pumping. It was discovered some years ago that if a small globule of mercury is introduced into the tube when this is very hot, the mercury will vaporise rapidly and carry away large quantities of the residual impure gas. This technique, which achieves an improved vacuum in a shorter time, has been extended to all the fluorescent tube pumping machines, and doses of mercury are now injected at two stages during pumping.

A substantial reduction in the amount of end blackening due to evaporation of free barium during life has been achieved ; in the present 80 watt tube there is hardly any detectable blackening during the first few thousand hours.

The luminous performance of high-voltage cold cathode tubes over the first 15,000 hours of life has been increased by 12 per cent.

MERCURY LAMPS.

High-pressure mercury vapour fluorescent lamps in wattages of 80 and 125 are now in factory production with the new barium-strontium-lithium-silicate phosphor, and similar lamps of higher wattage ratings are under development. This phosphor gives considerably improved colour rendering with the same efficiency as the plain mercury lamps. The new fluorescent types are interchangeable with the corresponding plain lamps as they have the same bulb size and 3-pin B.C. caps. The new type fluorescent 125 watt lamp is also available with a G.E.S. cap when required as a replacement for an earlier mercury fluorescent lamp of the same wattage.

SODIUM LAMPS.

Sodium lamps are giving long life and trouble-free performance, and efforts are being made continually to effect further improvements in view of the increasing use of these lamps for street lighting. Close attention is also being given to the circuit and other aspects of sodium lighting.

TUNGSTEN FILAMENT LAMPS.

Class A1 projector lamps of 500, 750 and 1,000 watts are now being developed with biplane filament formation in the 200-250 voltage range. This formation has been used in low-voltage lamps for many years, but the longer and thinner filament wire required for a high-voltage lamp greatly increased the risk of short circuiting; improvements in the stability of filament wire will, however, make high-voltage biplane lamps possible.

An unusual feature of a 1,000 watt lamp

* *G.E.C. Journal*, Vol. XX, No. 1, p. 49, January, 1953.

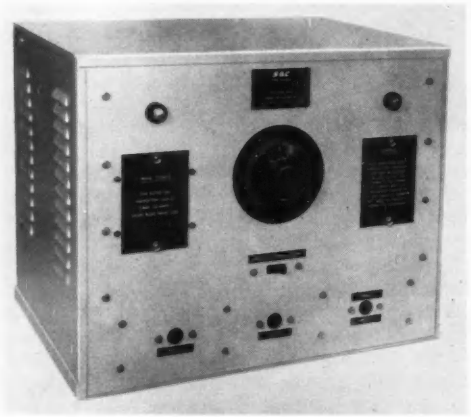

Fig. 80.—Central control equipment of the electronic dimming system.

developed for underwater lighting is that it operates in direct contact with the water. It has a grid filament and a spherical, 100 mm. diameter bulb of specially thin glass to prevent undue thermal stress. The bulb has a short neck, fitting tightly into a rubber tube inside which the electrical connections are made, and a reflector is used to control light distribution. This lamp has been used successfully for underwater television and has withstood pressures up to 600 lb./sq. in.

Lamps for use as photometric standards are being developed in co-operation with the National Physical Laboratory. The range includes lamps for use as standards of directional intensity and others as standards of luminous flux. Special construction techniques are employed to achieve an exceptionally constant level of performance.

Among other new Osram tungsten filament lamps are 40, 60 and 100 watt single coil Silverlight lamps, a 100 watt Rough Service lamp and a 75 watt Reflector Spotlight. The range of internally coloured lamps has also been extended and now includes 15 and 25 watt sizes, and Pygmy types.

Several modifications have been made to the battery-lamp range. Lens ends for 2·2 volt, ·25 amp. flashlamps, prefocus caps on 2·5 volt, ·3 amp. flashlamps and silica spraying of 24 volt, 12 watt bus lamps have been introduced, and yellow cadmium glass bulbs have been reintroduced as an alternative to clear-glass bulbs for certain car headlights.

GERMICIDAL TUBES.

Fifteen and thirty watt germicidal tubes have been marketed.

ELECTRO-LUMINESCENT PANELS.

Certain practical applications of electro-luminescent panels have been investigated. The panel consists of a glass plate on one side of which are coated successively : a transparent electrically conducting layer ; a layer of fluorescent material ; a dielectric layer ; and an opaque conducting layer. The fluorescent material is thus sandwiched between two conducting layers which are, in effect, the two plates of a capacitor. When

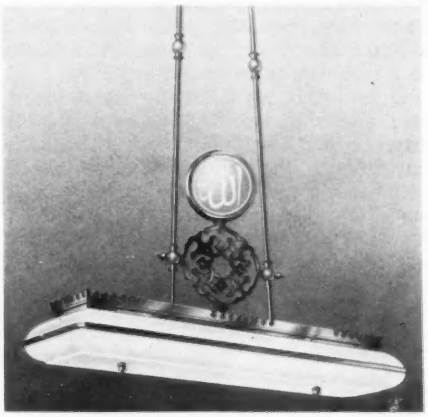

Fig. 81.—One of the special fittings for the cloisters of the Grand Mosque, Mecca.

Fig. 82.—One of the special floodlights for the courtyard of the Grand Mosque, Mecca.

an alternating voltage is applied the fluorescent material glows with a brightness which depends on the applied voltage and its frequency. The panels can be connected direct to 50 c.p.s. A.C. mains without any special auxiliary equipment.

DIMMING EQUIPMENT.

The recently developed electronic dimming equipment gives smooth control with either hot or cold cathode fluorescent tubes or a combination of both, from full light output to blackout. It eliminates the disadvantages of earlier dimming systems, where the discharge was apt to flicker at lower output levels and where there was also a noticeable jump between the minimum and blackout in dark surroundings.

Fig. 80 shows the central control unit of the system which is capable of dimming up to thirty-two 80 watt hot cathode tubes or the equivalent load in cold cathode lighting. For larger loads a number of these units may be ganged. Gas-filled triode valves are used with a patented grid control circuit. The equipment may be controlled manually by local or remote push-button, or alternatively it may be coupled to an automatic cycling apparatus in which a motor-operated controller and a bank of relays provide continuous colour changing effects of great variety and flexibility.

The auxiliary gear for each tube is in the standard G.E.C. " brick " section, easily accommodated in the gear channel of a normal fluorescent fitting. Only three supply wires are required and these may all be looped or paralleled over as many tubes as desired up to the full capacity of the equipment. Selective switching can be incorporated, enabling tubes to be switched in or out without interfering with the light output of others in circuit. The power factor of each tube circuit is individually corrected, giving maximum economy in wiring.

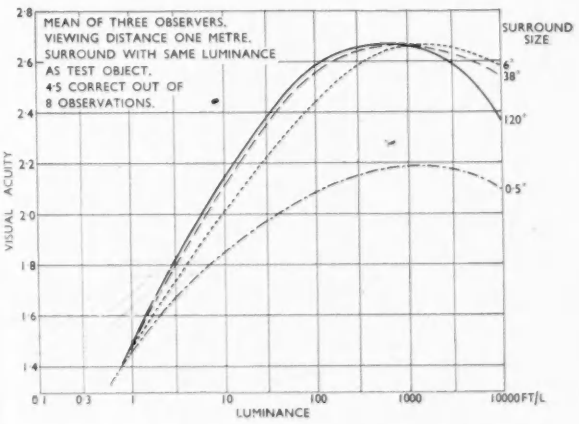

Fig. 83.—Graph showing some of the results of visual acuity tests at the Research Laboratories.

Fig. 84.—Main road lantern for use with tungsten filament lamp.

FITTINGS DESIGN.

One of the most outstanding contracts undertaken by the Fittings Design Department was for special lighting fittings for the Grand Mosque at Mecca. Only those who belong to the Moslem faith are allowed to visit the Mosque or even the city of Mecca, consequently the designer had to work from photographs and a pilgrim's map of the Mosque. In the cloisters 225 fluorescent pendant fittings (fig. 81) are to be installed, and general lighting in the courtyard will be provided by twenty-eight decorative fluorescent floodlights (fig. 82).

INTERIOR LIGHTING RESEARCH.

The study of apparent brightness, emphasis and modelling has continued at the Research Laboratories. Surveys on different interiors by night and day have been made, and several experiments have been carried out. A paper has been prepared describing the work, which is approaching the point at which a new quantitative approach to interior lighting may be possible.

VISUAL ACUITY.

This is another matter on which a long series of experiments has been carried out at the Laboratories. An observer is presented with a Landolt

broken circle (C) and asked to state the position in which the gap appears; the conditions of the experiment are varied over a wide range of brightness both in the immediate vicinity of the circle and in the general surround.

Fig. 85.—" Wembley " street lighting lantern, for use with a tungsten filament lamp.

Some of the results obtained are shown in fig. 83. It will be seen that as the luminance of the test object is increased, up to about 1,000 ft. lamberts, the observer's acuity increases. This accords with the result of previous investigations, but a new fact that emerges is that beyond this point the acuity falls. It will also be noted that a surround size of about 6° is nearly as effective as one much larger, which is contrary to the belief held in certain quarters that a very large surround is necessary. The full results of this work will be published at a later date.

EXTERIOR LIGHTING.

Fig. 84 shows a new lantern for main road lighting which is designed for use with a 300 or 500 watt clear tungsten filament lamp. The body is a single piece light alloy die-casting which can be supplied for top or side entry mounting. Both versions incorporate a drip baffle to prevent the entry of water which may condense in the supporting bracket. A die-cast light alloy refractor plate carries the single piece prismatic glass dome refractor, which is held by three spring supports.

In the lanterns shown in figs. 85 and 86, which have cast-iron bodies, the outer globe is supported by a cast-iron hinged ring with a quick release toggle catch. Spring clips hold the glass in the ring, and two gaskets ensure a weatherproof seal when the lantern is closed. The " Wembley " version is for use with a 300 or 500 watt clear tungsten filament lamp, and a white vitreous enamelled refractor plate supports the prismatic glass dome refractor. The " Difractor " lantern houses a 250 or 400 watt mercury MA/V lamp and has a prismatic glass bowl refractor, no inner dome refractor being required.

A range of fluorescent tube lanterns (fig. 87), designed for wall mounting, has been introduced for use where column mounting is impractical or undesirable. Models are available for two 2 ft. 40 watt or one or two 5 ft. 80 watt tubes. The aluminium girder framework is covered by aluminium sheet, and the lantern is totally enclosed by a hinged door, glazed with broad reeded glass and secured by stainless steel toggle catches. Optical control is by means of a removable anodised aluminium trough reflector. Lamp auxiliaries are mounted on a detachable tray within the body of the lantern.

A new development in street lighting is shown in fig. 88. This is a post top lantern which houses five 67½ watt cold cathode fluorescent tubes bent into " U " shape, and is approximately equivalent in light output to a similar lantern employing four 5 ft. 80 watt hot cathode tubes or a normal main road lantern with a 400 watt mercury lamp. The main part of its length is a reeded " Perspex " cylinder at the top of which is seated a

Fig. 86.—" Difractor " street lighting lantern, using a mercury MA/V lamp.

spun cover held in place by a finial. The top of the spigot cap is enlarged to the full diameter of the lantern and carries the transformers required to operate the tubes. All high-tension leads are contained within the lantern, and three safety devices are fitted. In view of the long life

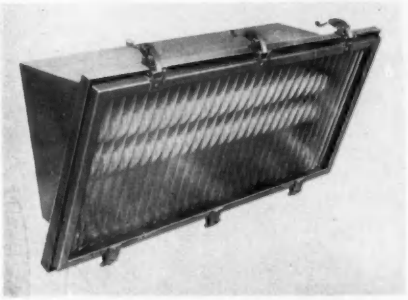

Fig. 87.—Fluorescent street lighting lantern designed for wall mounting. This model houses two 2 ft., 40 watt tubes.

expected of the tubes—more than 15,000 hours—and the fact that there are no starter switches, no doors have been provided as it is unlikely that the lantern will need to be opened more frequently than every three and a half years for maintenance.

Following tests in which the G.E.C. co-operated with the Ministry of Transport and the Ministry of Civil Aviation, a new specification has been issued for street lighting lanterns intended for use near aerodromes. The amount of light at and above the horizontal is restricted so that pilots cannot confuse the street lighting with aerodrome lights. Nevertheless, the light distribution below the horizontal must be suitable for lantern spacings associated with normal street lighting. The main road lantern shown in fig. 89, for use with a 140 watt sodium lamp, meets both requirements. It has a one-piece light alloy die-cast body, with a spun light alloy canopy providing a cut-off at about the horizontal. Light control is by " Perspex " refractor plates. This lantern is also suitable for waterside lighting where lights may have to be shielded.

Fig. 90 shows a side entry lantern designed specifically for side road and rural lighting in Canada. To meet local conditions it has several unusual features, notably a die-cast aluminium body of small overall diameter to minimise snow loading during the winter. A porcelain enamelled refractor plate carries a single-piece prismatic glass dome refractor, held by stainless steel clips in such a way as to leave the prismatic surfaces unobstructed. This lantern is intended for use with 85 to 300 watt Canadian incandescent lamps.

Several existing lanterns have been modified in design. For example, the post top mounting lantern (fig. 91), for four 2 ft. 20 or 40 watt

Fig. 88.—A new development in street lighting: post top lantern using cold cathode fluorescent tubes.

fluorescent tubes, has been improved in appearance by alterations to the shape of the top and bottom dishes. These modifications also enable bi-pin lampholders of spring loaded telescopic action to be accommodated. For a more decorative effect the top " Perspex " dish may be replaced by a light alloy mushroom-shaped spinning.

Changes in certain small lanterns for side-

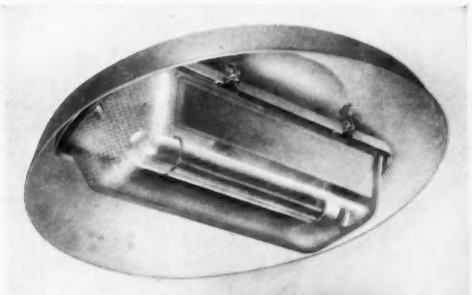

Fig. 89.—Main road lantern designed for use near aerodromes.

street lighting include the incorporation of a new hinged vitreous enamelled dome refractor plate. This carries the lamp focusing device die-cast in "Mazak" with the wattages cast in. Fig. 92 illustrates this feature in a post top lantern.

Fig. 90.—Lantern designed for side-road and rural lighting in Canada.

The recurrent problem of lighting very wide roads led to a recent experiment with floodlights mounted on normal columns on each side of the road. Six lanterns were placed at 115/120 ft. staggered spacing, each projecting a wide beam of light across the road with a maximum intensity of 400 cd. directed towards the opposite kerb. The amount of light directed up and down the road was quite small so there was practically no glare. Results indicated that with appropriate spacing, and using a specially designed optical system, an installation of this type could rival any conventional system. Moreover, there might be particular advantages where the road surface was rough.

Arising out of a study of the relative merits of different light sources for street lighting, an investigation was made at the Research Laboratories on relative discomfort glare.* Sources of about the same size and brightness as found in street-lighting lanterns were placed side by side, the sources being alike except that one used a high-pressure mercury vapour lamp and the other a sodium lamp. Viewed from about 80 feet the majority of observers found that the mercury lamp appeared the more glaring. A possible explanation of this effect is that the eye becomes more sensitive to light at the green and blue end of the spectrum as the source brightness increases ; a high brightness photometer is therefore being devised in order to make further tests.

* *G.E.C. Journal*, Vol. XX, No. 3, pp. 184-187, July, 1953.

NEW FLOODLIGHTS.

The projectors seen in fig. 93 have been specially developed for football floodlighting. Access to the lamp is from the back, and beam characteristics may be varied by the use of different mirrors and lamps.

Fig. 91. — The post top lantern with modified top and bottom dishes.

Fig. 92.—Side-street lantern showing die-cast lamp focusing device.

Fig. 93.—Floodlighting developed specially for use on football grounds.

An interesting feature of the new floodlight illustrated in fig. 94, for use with 80 or 140 watt sodium lamps, is that the front cover is made of sheet " Perspex " and does not require any metal framework. This arrangement is simple and effective but cannot be applied to high-wattage tungsten floodlights because of the high temperatures involved.

AERODROME LIGHTING.

A low-intensity elevated light (fig. 95) has been developed for either approach or runway lighting. It consists of a cylindrical " Perspex " refractor held between two aluminium spinnings mounted on a frangible base, and is very light in weight so as to cause only a slight impact in the event of collision. When equipped with a 12 volt 100 watt lamp it produces an omni-directional light distribution with a maximum intensity of about 1,200 cd. at 4° above the horizontal. With a smaller lamp it may also be used for taxiway lighting.

In collaboration with the Norwegian Air Ministry a special type of mounting has been devised for elevated runway and taxiway lights being supplied for use in Norway. A special base is used, mounted on an appropriate seating ring over a pit; the whole unit may be turned upside down manually and lowered into the pit so as to leave a flush surface over which a snow plough can operate.

The Glass Works have for some time been producing coloured glassware, particularly for aerodrome lights, to comply with the various Authorities' colour specifications. Coloured glasses in lighting fittings tend to run hotter than similar plain glasses because of the absorption of part of the light by the filter. This, together with the demand for higher powered

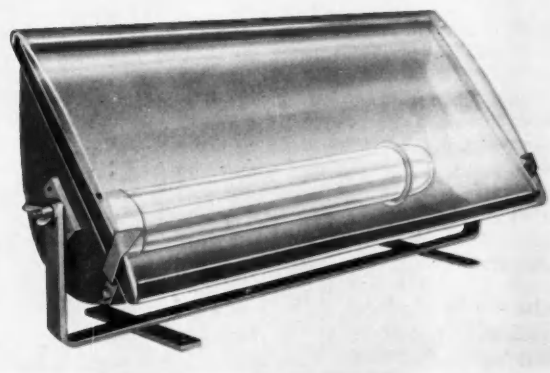

Fig. 94.—The new floodlight with " Perspex " front cover.

Fig. 95.—Low-intensity elevated light for aerodrome approach or runway lighting.

fittings of small size, has created a need for heat-resisting coloured glasses, and the Glass Works are experimenting with various melts to meet these new requirements. They have successfully developed a heat-resisting red glass for pressing, and considerable progress has been made towards the production of blue and green glassware for similar purposes.

MINE ROADWAY LIGHTING.

Tests on mine roadway lighting have continued both on site and in the model roadway at the Research Laboratories. Special fittings have been installed in a colliery for tests under service conditions and have given excellent results. For convenience they were not flameproof, but refractors of essentially the same optical design are being developed to fit into the new range of flameproof well glass fittings, to provide a flameproof roadway fitting with the required optical control.

SIGN LIGHTING.

Claude-General Neon Lights, Ltd., have introduced " Perspex " sign letters made in the form of inverted channels, similar in shape to the usual metal letters but illuminated from within by cold cathode fluorescent tubes. " Perspex " of various colours or combinations of colours can be used, thus giving an excellent daylight sign. At night, when illuminated, the letters appear as a three-dimensional coloured mass, uniformly flashed. They are weatherproof, light in weight, and normal rainfall serves to wash them. In particularly dirty locations they can, however, be cleaned easily with soap and water.

MARINE LIGHTING.

Three 13,000-ton passenger-cargo liners for the Ellerman & Bucknall line, City of Port Elizabeth, City of Exeter and City of York, are now at sea; all the lighting fittings have been designed and supplied by the Company. Osram fluorescent tubes are employed in the public rooms and it is worth recording that the lighting of these ships has been the subject of highly favourable comment at all the ports at which these ships have called.

Fig. 96.—Blended fluorescent and tungsten lighting in the drawing-room of the City of Port Elizabeth.

The Effect of Heat Treatment on the Electrical Properties of Germanium

By R. J. HODGKINSON, B.Sc., A.Inst. P.
G.E.C. Research Laboratories.

In order that the characteristics of semi-conducting devices, such as germanium diodes and triodes, may be controlled in manufacture it is essential that the electrical conductivity of the semi-conductor be controlled within close limits. It has been found that the conductivity is sensitive to heat treatment and an investigation of this effect has been part of the research programme. Some of the results obtained are described and the possible mechanisms governing the behaviour are discussed.

INTRODUCTION.

THE electrical conductivity of germanium is controlled by the impurities present in it. For example, arsenic is an impurity which is particularly important from a practical point of view. Each arsenic atom present contributes one electron to take part in electrical conductivity. The range of conductivity which is used for germanium diodes and triodes is about 0·2 mho cm^{-1} to 0·1 mho cm^{-1}. The number, n, of free electrons present per cubic centimetre of germanium can be calculated approximately from the equation :

$$n = \frac{\sigma}{e\mu} \qquad (1)$$

where σ = electrical conductivity
μ = electron mobility (i.e. velocity acquired by an electron in unit field in germanium).
= 3,600 cm^2/volt-sec.
e = electronic charge
= $1{\cdot}59 \times 10^{-20}$ e.m.u.

Thus in material of 0·2 mho cm^{-1} conductivity the number, n, of electrons taking part in the conduction is $3{\cdot}6 \times 10^{14}$/cc.

There are $4{\cdot}52 \times 10^{22}$ atoms in one cubic centimetre of germanium crystal; a conductivity of 0·2 mho cm^{-1} therefore corresponds to about 1 impurity atom in 10^8 germanium atoms. The germanium has therefore to be very pure indeed.

Impurities in germanium can act in two ways : as "donors" or as "acceptors". Donors give rise to electron conduction, and acceptors give rise to a phenomenon known as "hole" conduction.

To understand hole conduction, it is best to consider the rôle played by the electrons in a crystal of germanium. Each atom has four nearest neighbours, equidistant from it, and arranged so that they are at the corners of a regular tetrahedron. To each atom belong four outer electrons, and one of these is shared with each of the nearest neighbours. The atom also receives a share in one electron from each of its nearest neighbours. Thus each atom has two electrons orbiting round itself and each of its nearest neighbours. These electrons cause the atoms to be bound one to the other and are known as the "valence" or binding electrons. The quantum theory shows that an electron cannot be freed from one of these orbits without receiving a certain minimum amount of energy, since a "forbidden" range of energies exists between that possessed by electrons in the orbits, and that needed by electrons to be free within the crystal. This energy can be supplied by light entering the crystal, or from the thermal energy of the crystal. When the temperature of the crystal is raised from absolute zero, some of the electrons will leave their valence orbits and become free.

If impurities of the acceptor type are present, they provide empty "allowed" electron levels within the normally forbidden energy range. The energy required for an electron to reach one of these "acceptor levels" from a valence orbit is only a small fraction of that required to set it free within the crystal. Thus, as the temperature of the crystal is raised, many more electrons will leave the valence orbits if acceptor impurities are present. These electrons are bound, and cannot take part in the conduction, but a valence orbit which has been vacated can be filled by an electron from a neighbouring valence orbit, which in its turn can be filled by an electron from a third orbit. Thus the unoccupied orbit or "hole" is free to wander through

the crystal. If an electric field is applied to the crystal, the holes will appear to move under the influence of the electric field ; and it can be shown that a hole will act as if it were a positively charged electron.

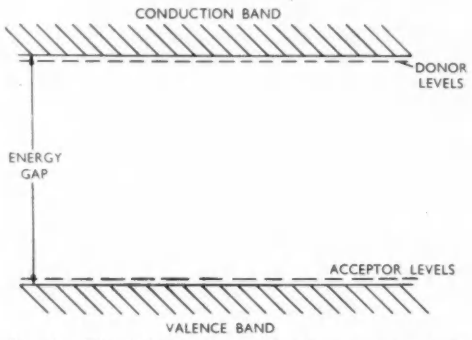

Fig. 1.—The " band picture " of energy levels in semi-conductors.

The picture most frequently used to illustrate electrons and holes in a semi-conductor such as germanium is the " band picture ", which is shown in fig. 1. At the bottom of the diagram is the valence band, which consists of the allowed energy levels supplied by the valence orbits. The individual levels within the band are so close together, that the band can be regarded as forming a continuous range of allowed energies. Above the valence band is a range of energies which an electron in a pure crystal cannot acquire. This forbidden range or " energy gap " is followed by another range of allowed energies, which like the valence band can be regarded as being continuous. This band is known as the conduction band. It is usually almost empty, and electrons in it are free to wander about the crystal, and give rise to electronic conduction in the presence of an electric field. In an impure crystal, two additional sets of allowed electron levels arise within the normally forbidden energy gap : donor levels and acceptor levels. The latter, which have already been discussed, lie just above the valence band. Donor levels arise from the presence of certain types of impurity, which supply filled electronic energy levels just below the conduction band. The electrons can easily be excited from these levels to the conduction band.

If acceptor levels are numerically in excess of donor levels, hole conduction in the valence band takes place, and the material is said to be " *p*-type ". If donor levels are in excess, electron conduction takes place, and the material is said to be " *n*-type ". In most cases which will be considered, the density, i.e. number per cc., of " current carriers " (holes or electrons) is the numerical difference between the density of donors, n_d, and density of acceptors, n_a.

The electrical properties of very pure germanium may be changed by heat treatment. These changes indicate that acceptor centres are formed in a concentration which increases as the temperature of heat treatment is increased. These centres are commonly described as " thermal acceptors ".

In the preparation of germanium for use in diodes and triodes, heat has inevitably to be used at some stage : in the reduction of the oxide, in the melting of the germanium powder, or in the growth of single crystals. In addition, a forming treatment is used in which pulses of electrical energy are passed through the point contacts of germanium diodes and triodes, raising the point contact momentarily to a high temperature. Thermal acceptors might be of considerable influence in some of these processes and therefore a study of the phenomenon was included in the programme of research aimed at providing the background knowledge necessary in the development of the devices. This article is intended to give an example of the kind of work which is included in such a programme.

It is proposed to give a brief account of some experiments which have been carried out in

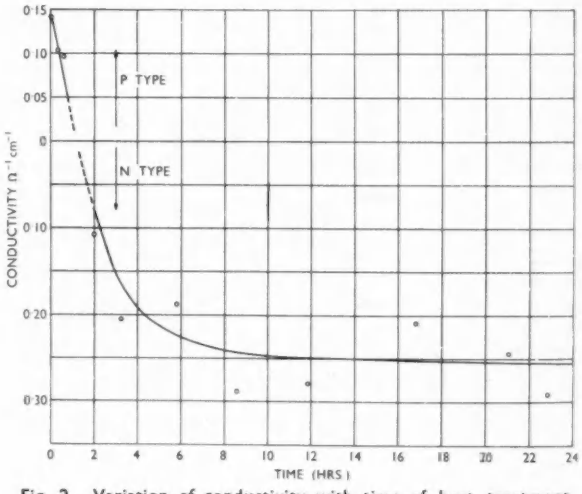

Fig. 2.—Variation of conductivity with time of heat treatment at 550 deg. C.

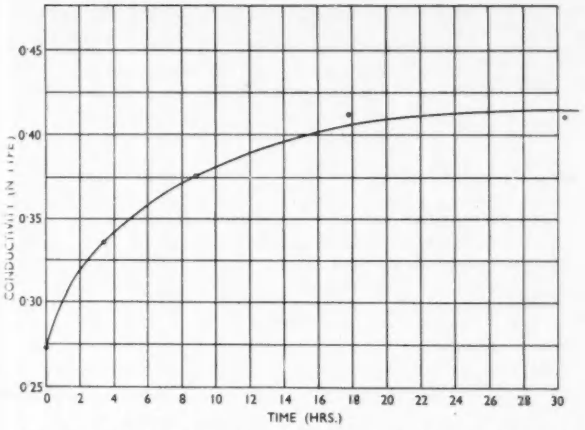

Fig. 3.—Variation of conductivity with time of heat treatment at 450 deg. C.

the Laboratories and to compare the results with those obtained by other investigators. The exact mechanism of formation of thermal acceptors is not yet fully understood ; the various ideas which have been suggested to account for their formation will be briefly indicated.

EXPERIMENTAL.

The experiments were simple, they consisted in heat-treating a specimen for a given time at a given temperature ; cooling it quickly to room temperature, and then measuring its electrical conductivity. This experiment was then repeated at various temperatures and for various times of heat treatment. In order to measure the conductivity with sufficient accuracy the specimens were ground accurately to size and measurements were made at a controlled temperature of 30 deg. C. in a dry box.

Some typical results are given in figs. 2 and 3. These figures refer to the same piece of germanium. When first cut from a single crystal taken from the growing apparatus it was *p*-type of 7 ohm-cm. resistivity. It was then heat-treated (in nitrogen to prevent oxidation) at 550 deg. C. and from time to time it was removed from the oven and its conductivity measured at room temperature. At first the conductivity decreased but subsequently it increased ; at the same time the specimen changed from *p*-type to *n*-type. After 22 hours the conductivity was approximately constant and the temperature of heat treatment was reduced to 450 deg. C. As can be seen from fig. 3 a further increase in conductivity took place.

The density of charge carriers in the specimen used can be calculated from the electrical conductivity by using the simple expression $n = \frac{\sigma}{e\mu}$.

Unless extremely impure germanium is used, it can be shown that in the region of room temperature, n is equal to the difference between the densities of donor and acceptor impurities present. From the measured values of conductivity, then, the density of charge carriers n may be calculated, and

$n = n_d - n_a$

n_d = density of donor centres

n_a = density of acceptor centres.

Thus in the experiments summarised in fig. 2, the heat treatment reduced n_a, the number of acceptor centres. When the specimen was *p*-type the reduction in number of acceptors decreased the difference between n_a and n_d. This decreased the density of current carriers (holes). At the conductivity minimum, n_a became equal to n_d, and when n_a decreased on further heat treatment, the specimen became *n*-type, and the conductivity then increased as the heat treatment progressed. On heat treatment at 450 deg. C. still more acceptors were removed, and the conductivity increased still further.

Figs. 4 and 5 show the results of 2 and 3 plotted in terms of density of carriers present in the specimen. It can be seen that the density

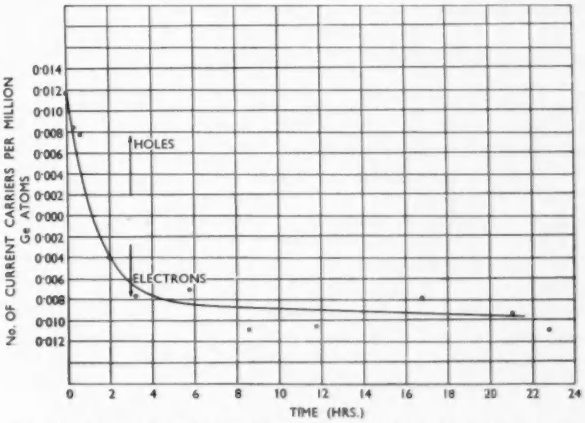

Fig. 4.—Variation of the number of carriers in a piece single-crystal germanium with time of heat treatment of at 550 deg. C. in nitrogen.

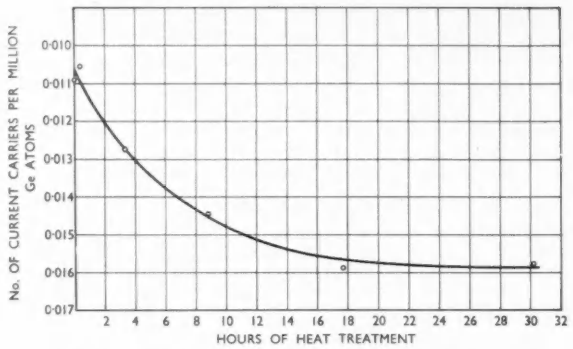

Fig. 5.—Heat treatment of the germanium specimen at 450 deg. C. in nitrogen.

of carriers changes at first quickly and then less quickly as the specimen is heat-treated. Finally the density of carriers tends asymptotically to the equilibrium value for the temperature of heat treatment.

Fig. 6 shows the equilibrium value of the conductivity of a specimen for a series of different temperatures of heat treatment. It will be noted that the first and last experiments show that the conductivity returns approximately to its original value at the low temperatures after the series of heat treatments. As in the samples used the impurities present were far too few to be detected by available analytical techniques, only the changes in n_a can be directly deduced from the measurements. However, the changes in n_a are quite large between 500 deg. C. and 800 deg. C. and an estimate of the absolute number of acceptor centres formed by the various heat treatments may be made as follows. If it be assumed that n_d remains constant throughout the experiment, and this appears to be a reasonable assumption because of the reversibility of the phenomenon, then the difference between the density of carriers at, say, 550 deg. C. and 850 deg. C. gives directly the difference in density of acceptor centres at those two temperatures. When the logarithm of these differences is plotted against the reciprocal of the absolute temperature, the points fall on a straight line above about 650 deg. C. (fig. 7).

It is reasonable to assume that if the absolute numbers of acceptor centres were known, all the observations would lie on a straight line. An estimate of the absolute number at 550 deg. C. is therefore made by reading off from the graph the number appropriate to that temperature. This number is so small compared with the numbers obtained at the higher temperatures that the differences turn out to be very close to the estimated absolute numbers. Typical corrected curves for absolute numbers against temperature are given in fig. 8.

The temperature variation of the density of thermal acceptors is therefore given by a relation of the type :

$$n = A \exp\left(-\frac{E}{kT}\right) \qquad (2)$$

where n = number of thermal acceptors per c.c.

A = constant

E = constant

k = Boltzmann's constant ($=\frac{R}{N}$, where R = gas constant, per gram molecule, and N = number of molecules in a gram molecule).

At the time of producing these results, it appeared that the thermal acceptors might be identified with lattice defects. Lattice defects are formed when an atom leaves its position in the crystal lattice and either moves to an interstitial position as in fig. 9(a) or diffuses to the surface as in fig. 9(b). The former type of defect is known as a Frenkel defect and the latter as a Schottky. Both the Frenkel and

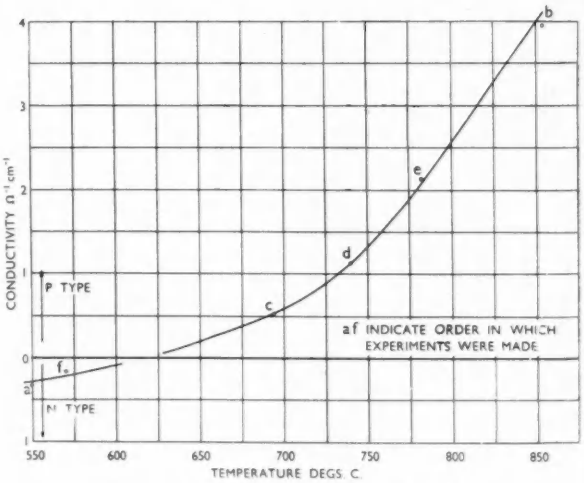

Fig. 6.—Variation of conductivity of specimen 7 with temperature of heat treatment.

Schottky theories lead to equations of the form of equation 2.

APPARENT DECREASE IN DENSITY OF THERMAL ACCEPTORS AT HIGH TEMPERATURE.

When the range of heat treatment temperatures was extended above 850 deg. C., it was found that the density of thermal acceptors rose to a maximum at about 880 deg. C., after which the density apparently decreased very rapidly. This can be seen in fig. 10 where the density of thermal acceptors is plotted against $\frac{1}{T}$ for the range of temperatures 550 deg. C., to 930 deg. C. This behaviour at high temperatures is important because it indicates that more than one factor influences the concentration of thermal acceptors. However, before pursuing this point, some other published observations will be considered.

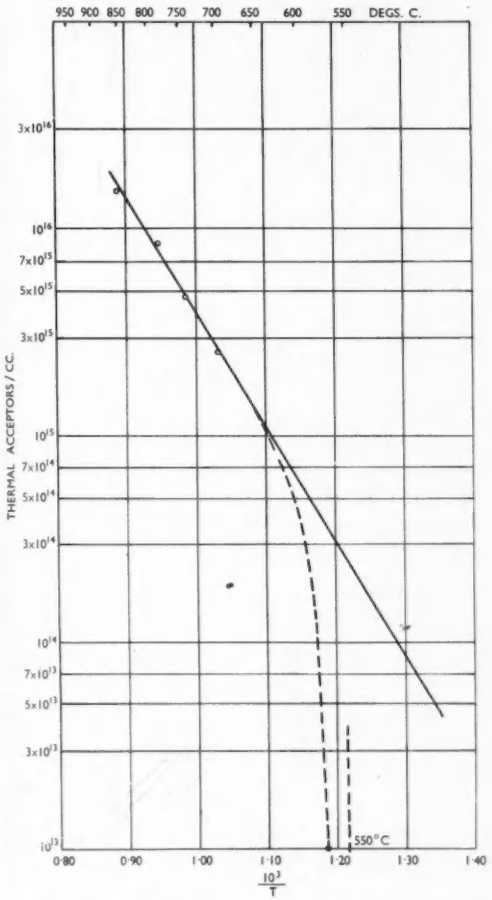

Fig. 7.—Number of thermal acceptors expressed as difference from 550 deg. C.

COMPARISON WITH THE WORK OF OTHER INVESTIGATORS.

The temperature variation of the density of thermal acceptors has been investigated by several other experimenters, notably Fuller, Theuerer and Van Roosbroeck,[1] Fuller and Struthers[2] and Goldberg[3]. The variation between 550 deg. C. and 850 deg. C. agrees fairly well with that shown in fig. 4. There is no report of the high temperature decrease. However, Goldberg finds a flattening out of the curve, which he attributes to inefficient quenching, and there is a point on one of the curves of Fuller and Struthers which could be attributed to a high temperature decrease. In fig. 11, our measurements are plotted together with the results of Fuller and Struthers, and of Goldberg. It will be seen that the point which appears to be anomalous on Fuller and Struthers' graph, and

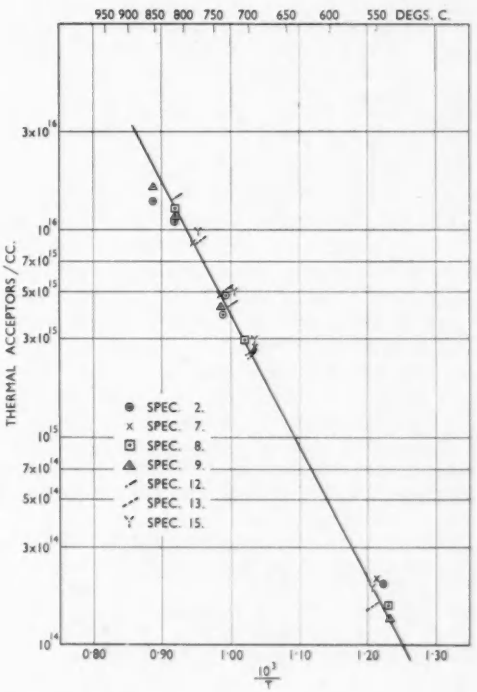

Fig. 8.—Density of thermal acceptors in equilibrium.

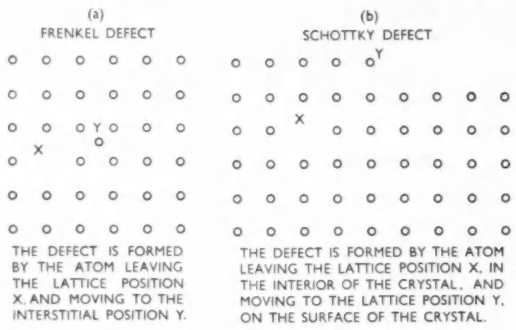
(a)
FRENKEL DEFECT
THE DEFECT IS FORMED BY THE ATOM LEAVING THE LATTICE POSITION X, AND MOVING TO THE INTERSTITIAL POSITION Y.
(b)
SCHOTTKY DEFECT
THE DEFECT IS FORMED BY THE ATOM LEAVING THE LATTICE POSITION X, IN THE INTERIOR OF THE CRYSTAL, AND MOVING TO THE LATTICE POSITION Y, ON THE SURFACE OF THE CRYSTAL.

Fig. 9.—Formation of lattice defects.

the "flattening out" point on Goldberg's graph appear to lie in the high-temperature region where the number of thermal acceptors appears to decrease.

THE ORIGIN OF THERMAL ACCEPTOR LEVELS.

The behaviour of thermal acceptors in germanium may now be summarised as follows:

(1) Up to about 850 deg. C. the number of thermal acceptors in equilibrium increases, and is determined approximately by the equation:

$$n = A \exp\left(-\frac{E}{kT}\right)$$

(2) The number can be changed reversibly, i.e. if a specimen is brought to equilibrium at one temperature, then subjected to a series of heat treatments at other temperatures, and finally brought to equilibrium again at the original temperature, the same number of thermal acceptors is again found.

(3) Above about 880 deg. C. the number of thermal acceptors in equilibrium appears to decrease as the temperature rises.

In addition to the lattice defect hypothesis mentioned above, there are two other hypotheses which can account for the behaviour summarised under (1) and (2) above.

The first of these[4] suggested that the thermal acceptors were impurity atoms which could be "activated" or "de-activated" by high- or low-temperature heat treatment respectively. Apart from the fact that it is known that germanium may contain a little dissolved oxygen, there was no experimental evidence to support this hypothesis.

The second hypothesis is that the thermal acceptors arise from the presence of copper atoms which it is suggested have a very limited solubility in germanium; the solubility at any temperature being given by the number of thermal acceptors found to be in equilibrium at that temperature, i.e. the solubility is of the order 1 copper atom in 10^7 germanium atoms.

This hypothesis has been supported by considerable experimental evidence. Fuller and others have shown that the thermal acceptors appear to diffuse into the material from the surface[1&2] and further that the diffusion coefficient is the same, within experimental error, for the thermal acceptors and for copper. They have also shown that if the surface of germanium is slightly contaminated with a very dilute solution of a radio-active copper salt, and then heat-treated, the concentration of copper found to have diffused into the germanium is the same as the apparent number of thermal acceptors.

Seiler and others[5] have made similar experiments and have suggested that, not only copper,

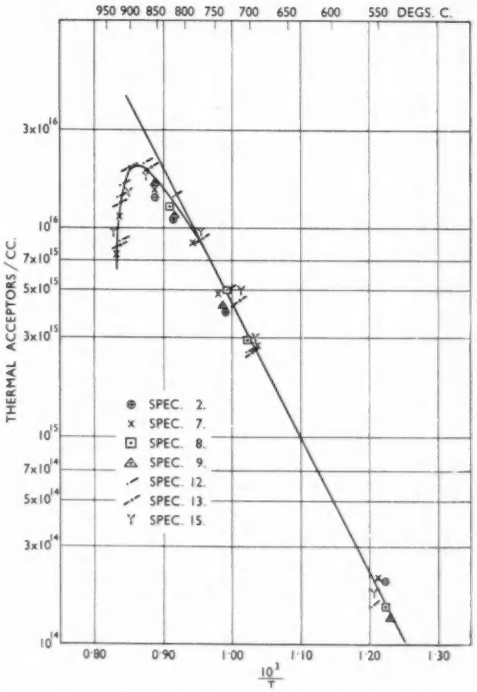

Fig. 10.—Densities of thermal acceptors in germanium between 550 deg. C. and 930 deg. C.

but potassium, magnesium and iron may also give rise to thermal acceptors.

Thus it is fairly well established that impurities, and in particular copper, play an important rôle in the formation of thermal acceptors, at least below 880 deg. C., although the very low limit of solubility of the copper is somewhat surprising at first sight. In addition to the evidence for the decrease in the density of acceptors above this temperature, there is in the account of Fuller and Struthers,[2] a record of one observation of a decrease in the solubility of copper above 900 deg. C., corresponding to a similar decrease in the number of acceptors.

If thermal acceptors are copper atoms, it should be possible to explain the temperature variation of the numbers of thermal acceptors in terms of equilibrium in the system copper-germanium. Fig. 12 shows the phase diagram for this system. The assumption that thermal acceptors are copper atoms would indicate that there is another phase at the extreme right-hand side of the diagram, this phase being a solid solution of copper in germanium. The limits of solubility for this phase are much too small to be indicated on the diagram, the appropriate portion of which is shown on a greatly enlarged scale in fig. 13 ; our results for the concentration of thermal acceptors have been used to give the boundary of the phase.

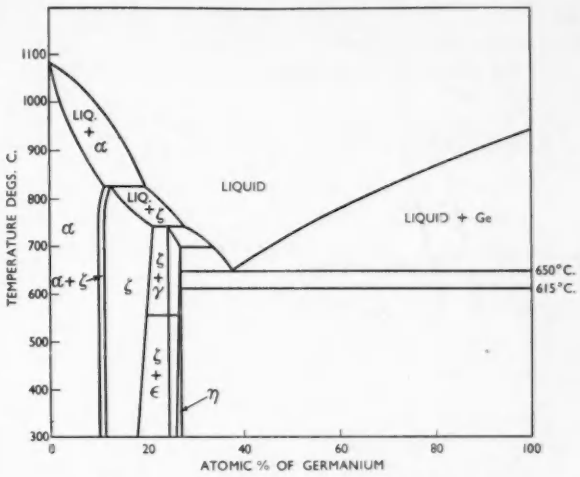

Fig. 12.—Copper-germanium phase diagram.

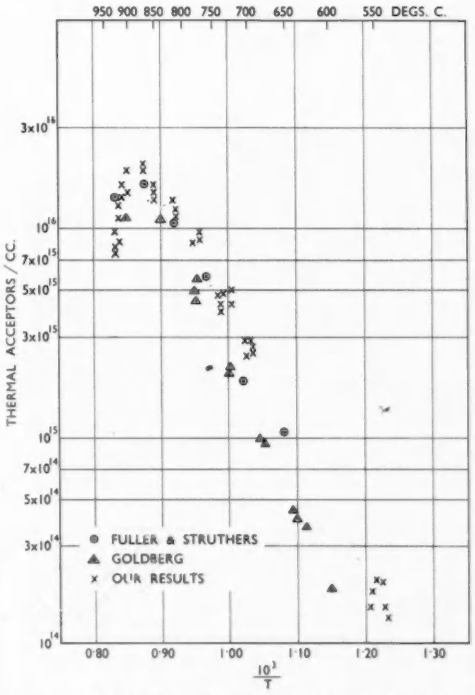

Fig. 11.—Comparison of the thermal acceptor densities found by different investigators.

These solid solutions may be discussed theoretically in terms of energy of a copper atom in solution in a germanium crystal, and the disorder of the arrangement of the copper and germanium atoms. It is found that below a certain temperature, the saturation solubility could be given approximately by a relation of the form of equation (2).

$$n = A \exp\left(-\frac{E}{kT}\right)$$

It is also found that the solid solubility must fall to zero as the melting point is approached. The form of the temperature variation of thermal acceptors is thus in accord with this theoretical treatment. However, it will be clear that extremely careful experiments in which great precautions are taken to avoid contamination by other materials will be neces-

sary before it can be claimed that the phenomenon of thermal acceptors is fully understood.

Certain of the work described in this article was performed for the Admiralty and the author's thanks are due to them for permission to publish the results.

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4. See e.g. TORREY and WHITMER, " Crystal Rectifiers," p. 365—McGraw-Hill.
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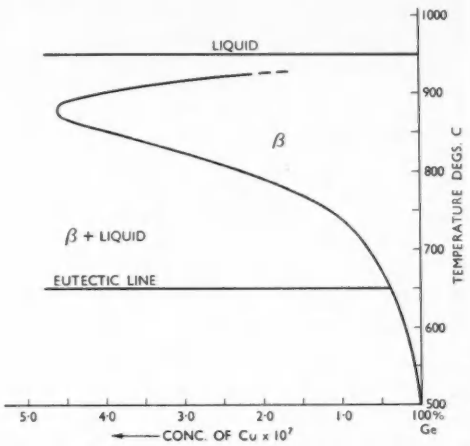

Fig. 13.—Part of copper-germanium phase diagram

Railway Lighting

Illumination of Willesden carriage sidings, British Railways, London Midland Region, by means of 333 " Uniway " lanterns mounted on concrete gantries.

Development of Electric Whaling Forerunners

By REGINALD BEAN
Pirelli-General Cable Works, Ltd.

The traditional method of catching whales has been by the use of an explosive head harpoon. This is a lengthy, rather inefficient procedure which inflicts great suffering on the whale. Recently the new technique of electrocution has been developed which enables the whale to be painlessly despatched in a matter of minutes.

This posed the question of how to produce an extensible electric cable which would stretch to the same extent as the nylon cable inside which it is carried, namely 45 per cent of its original length. This article describes the ingenious way in which this considerable problem was solved.

In recent years, and particularly since the last war, determined efforts have been made to develop a practical method of catching whales by means of electrocution which will supersede the traditional, somewhat inefficient and inhumane procedure involving the use of an explosive head harpoon. A brief article on this subject has already appeared in this Journal* in which an outline was given of the special equipment which has had to be designed and built for this purpose.

One of the most difficult problems which had to be overcome concerned the production of an extensible electric cable for inclusion in a nylon forerunner. It should be explained that "forerunner" is the name given to the rope which is actually attached to the harpoon, and, when the subject was originally discussed with Hector Whaling, Ltd. (formerly United Whalers, Ltd.), nylon forerunners were already in use, and because of the ease with which they could be handled under Antarctic conditions were in great favour with the whaling gunners. At that time, it was the intention of the whaling company to employ the existing heavy gun for their initial experiments, replacing the explosive heads of the harpoons with electrical heads. In what follows it is proposed to trace in some detail the events which led up to the design and introduction of the Pirelli-General patented forerunner.

At the outset, the dearth of information concerning the critical voltage and current required to electrocute a whale presented a very real problem. Although it was known that a patent had been taken out in London as long ago as 1868, and that much experimental work had been undertaken on this subject in subsequent years, the vital details were not available. Many claims were made from time to time, during the period extending up to 1938, but, apart from announcements of the number of whales "taken", any data likely to be of value to rivals in this field were very naturally not published.

Accordingly, the Pirelli-General Cable Company found itself faced with the formidable task of designing a cable with no real information upon which to work. There remained one basic fact : the request for an electric cable to be included within a nylon rope, capable of stretching, with the rope, as much as 45 per cent and able quickly to regain its original length in conformity with the nylon rope which recovers almost immediately when the mechanical load is removed. At this stage it was obvious that some assumptions would have to be made, both with regard to the voltage and current, and allowances made for the rise in temperature of the conductor due to the flow of current, and the loss of power occasioned by the voltage drop. Other factors which had to receive careful consideration were the dimensions and weight of the cable.

The ropes attached to the explosive head harpoons were already somewhat bulky, and as it was intended to include three electric cables, one in each strand of the rope, a small cable was obviously essential otherwise the composite rope would be extremely difficult to handle by reason of its increased size. Moreover, any undue increase in the weight would have a detrimental effect on the flight and penetrating power of the harpoon.

After a considerable amount of thought and calculation, a cable was designed and manufactured which would stretch 45 per cent of its original length without extending the copper

* "The Electrocution of Whales." By ROBERT MARSDEN, *G.E.C. Journal*, Vol. XIX, No. 2, April, 1952.

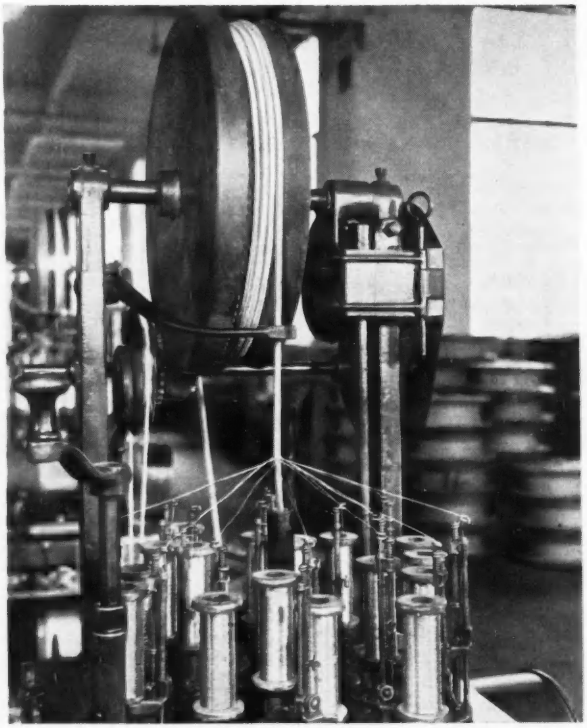

Fig. 1.—Tinned copper wires being braided on the rubber core.

wires beyond their elastic limit of less than 1 per cent. On test, an elongation of 60 per cent was obtained before fracture of the wires occurred.

It is appropriate to explain at this stage that the phenomenal extension of the copper conductor was achieved by the simple but effective device of forming it from a number of fine tinned copper wires applied in braided formation around a vulcanised rubber centre or core (fig. 1). Over the braided wires there followed rubber insulation (fig. 2) and finally a braid of fine nylon cord.

Three lengths of this extensible cable were produced and despatched to one of the leading ropemakers for inclusion in a nylon forerunner. Tensile tests on the final product proved that the cable would function perfectly even after the rope had actually fractured. Although the cables were relatively small, however, the " electrified forerunner " was rather bulky because a similar mass of nylon had been used as with the ordinary forerunner. This was considered by the ropemakers to be essential in order to ensure an equally strong rope.

Trials conducted in the Antarctic by the whaling company led them to believe that much lighter equipment could be expected to give satisfactory results. With this object in view, work was begun on the design of a new gun, lighter harpoons and also a lighter and less expensive electrified forerunner. As was to be expected, the usual " teething troubles " were encountered, but eventually a new type of spigot gun was evolved and an entirely new electric harpoon was produced.

Attempts to produce a light electrified forerunner, however, met with little success. In tackling this problem it was thought that a much less bulky forerunner would do all that was required, since a whale becomes paralysed once the electric harpoon penetrates its body and, in conse-

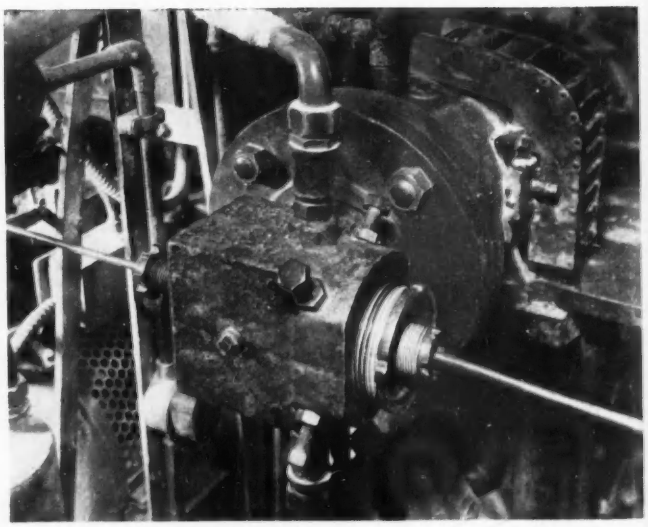

Fig. 2.—Application of unvulcanised rubber over the conductor.

quence, does not struggle, attempt to dive, or swim away. Electric manilla forerunners were then produced by another firm of ropemakers for trials with the prototype spigot gun which had a much higher muzzle velocity than the heavier guns in general use.

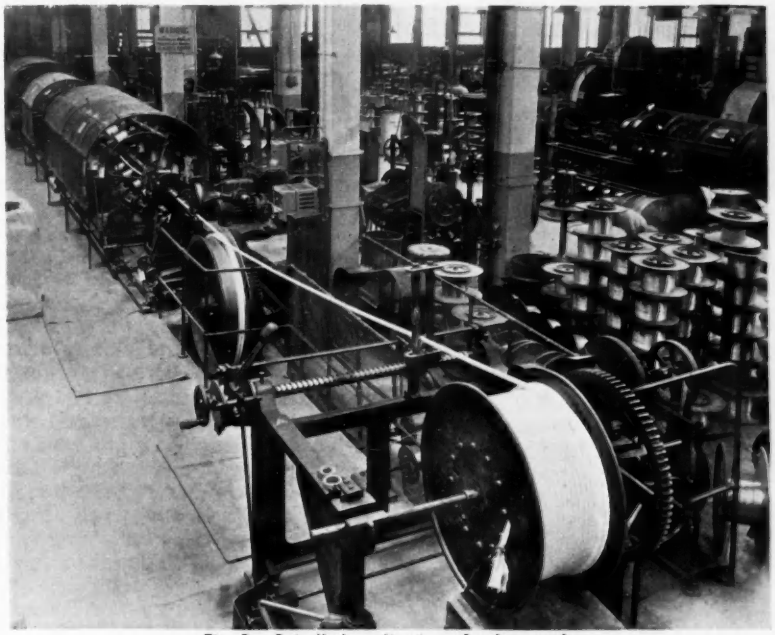

Fig. 3.—Spiralled application of nylon cords.

These manilla ropes were much smaller than their nylon counterparts, although because of the heavy current it was assumed they would have to carry, the electric cables could not be reduced in size. This meant that there would be much less covering for these cables in the rope, a fact that quickly became apparent after firing. The first rope tried did not behave well in flight, and there was a tendency for the cables to protrude from the rope in " knuckles ". The rope itself also tended to knuckle, leaving the cables unprotected. This condition could not be tolerated because even if the conductors remained intact until the whale was electrocuted the cables would be severed when winching the rope inboard. Several ropes were tried but each developed the same type of fault after the first, second or third shot. The ropemakers attempted to rectify the defect in a variety of ways. A single cable placed in the centre of both three- and four-strand ropes did not materially improve matters. Clockwise and anti-clockwise stranding, with one cable in each strand of the ropes, still produced the same fault. Finally, a tighter twist was introduced and trials on the gun range led the ropemakers to believe they had solved this very difficult problem. Subsequent trials during an actual whaling expedition, however, proved beyond any doubt that a cure had not been effected, as the fault persisted. In addition, there was a tendency for the forerunner to pay out in tangled masses, thus considerably reducing the range.

During this experimental period, as each modified forerunner was produced, it was subjected to actual firing trials. These consisted in coiling the forerunner in front of the gun with one end suitably anchored and the other attached to a harpoon. On firing the gun, the flight of the harpoon was carefully watched for any tendency to develop tail spin or wobble, as was also the forerunner to assess its flight and paying out properties. The forerunner was then examined for damage to itself or the included cables.

In view of the interest which it had in respect of the cables, representatives from the Pirelli-General Cable Works were invited to witness a large number of the trials and, as failure followed

failure, not a little criticism of the cables was naturally received. The most minute difference between one length of cable and another which, in the electric cable industry, would have been accepted without question as a normal manufacturing variation, was cited as being sufficient to make all the difference between failure or success.

Throughout this very trying period the Company maintained that it was impossible to improve the design of the cable, and although, in actual fact, the contract to design a cable capable of an elongation of 45 per cent of its original length had been strictly fulfilled, the Company was anxious to continue co-operating until success had been achieved. In fairness to the ropemakers it must be said that they were disposed to regard an electrified forerunner primarily as a rope, whereas the Company was, in fact, inclined to consider it a reinforced electric cable. This basic divergence of view was sufficient to explain the two entirely different approaches to the subject.

Rightly or wrongly, the designers of the cable believed that the usual type of three- or four-strand rope, on being mechanically stressed, would have a tendency to untwist or de-strand, but, in so doing, the individual strands would become more tightly twisted because the material forming these unit strands is twisted in the opposite direction to that of the final lay-up of the rope. In their opinion this was responsible for the knuckles found in the ropes after they had been fired. Moreover, this theory appeared to be confirmed by the fact that some of the ropes did introduce tail spin to the harpoons. Additional evidence of the cables having been twisted was afforded by an inspection of those in which the conductors were only partially severed, since the wires forming the braided conductor which had fractured were all lying in one direction, while those in the opposite direction remained intact.

An analysis of the results thus far obtained now convinced Pirelli-General that a rope of orthodox construction would be certain to have an extremely detrimental effect on such a lightly constructed cable. Adopting electric cable making technique, therefore, they set about designing a forerunner which would not twist whatever the mechanical load. The first essential was a perfectly balanced construction which was obtained by applying the rope-forming material —manilla, hemp, sisal, nylon, terylene, silk or cotton, as the case might be—in an even number of concentric layers around the extensible cable, the number of layers depending upon the material used and the desired strength. The necessity of employing an even number of layers is obvious, since the tendency of any one layer to introduce torque into the forerunner when stressed would be neutralised by the adjacent layer, each layer being applied in the opposite direction to the preceding layer. To obtain positive neutralisation, however, the mass of

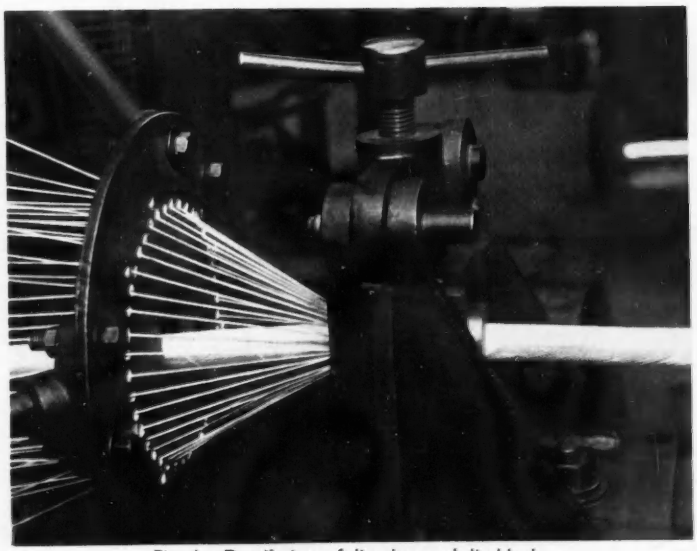

Fig. 4.—Detail view of die-plate and die block.

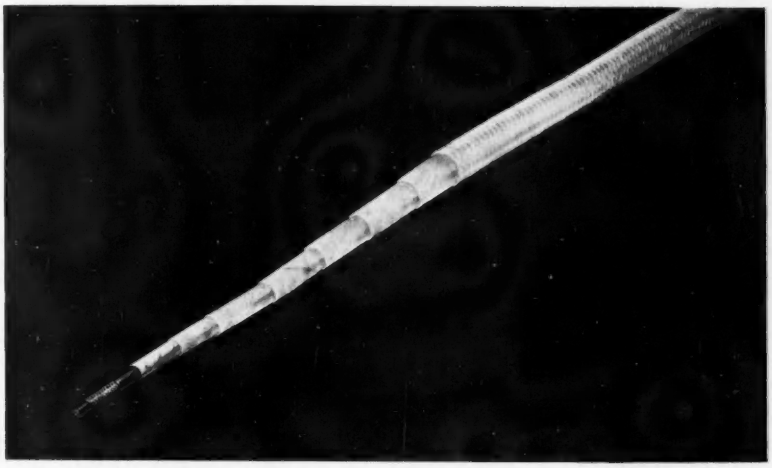

Fig. 5.—End of the forerunner, stepped to show the build up. The braided conductor on the rubber core is seen on the left.

yarn or cord in any two layers of a pair must be identical.

Considerable importance was attached to the flexibility of the forerunner, and, although the basic design tended to induce this attribute, it was further improved by arranging for every layer of yarn or cord to be applied spirally with a constant and carefully predetermined angle of inclination to the axis of the forerunner (figs. 3, 4, 5). This mode of construction also ensured that the mechanical load imposed on the forerunner when in service would be distributed equally to every yarn or cord.

Finally, a braiding of the same rope-forming material was applied as an outside protective covering (fig. 6). This served a double purpose in that it prevented displacement of the underlying spiralled coverings during handling, and also ensured compactness of the forerunner even when subjected to extremely acute bending.

Confident that this extensible cable would do everything required of it, Pirelli-General decided to produce a forerunner employing a quality of hemp commonly used in the cable-making industry, and, on its completion, approached the whaling company with a view to their subjecting it to any tests they thought fit. Arrangements were quickly made with the

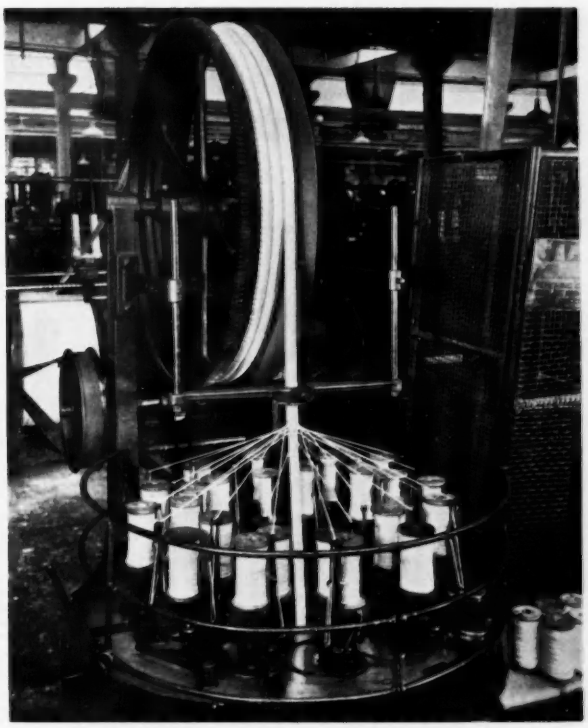

Fig. 6.—Application of the external nylon cord braid.

makers of the spigot gun for firing trials on the range. It was therefore most gratifying to note that, after repeated firing, this prototype forerunner showed no signs of damage. It was in due course returned to the Works, and after a thorough examination found to be in perfect condition.

The whaling company was so impressed with the result that the Company was asked to produce two electrified forerunners, one in nylon and the other in the relatively new terylene. These forerunners, together with others of orthodox construction, were used during an actual whaling expedition off the west coast of Africa. The behaviour of the two forerunners of Pirelli-General construction was far superior to that of the others, and exceeded all expectations.

It must be recorded with not a little satisfaction that no modification at all has been found necessary in the design of this forerunner. As only one cable is employed in each forerunner, in place of the three in parallel used with the conventional rope construction, it was considered advisable slightly to increase the number of wires forming the conductor.

It is not too much to claim that unless such an extensible forerunner had been produced, the whole scheme of whale catching by the modern method of electrocution would have been, if not impossible, at the least indefinitely delayed.

Fig. 7.—Stack of forerunners awaiting shipment.

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